STRUCTURE, SURFACE AND DRAINAGE IN SOUTH-EAST ENGLAND

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PREFACE

In 1939 the Institute of British Geographers published our monograph entitled 'Structure, Surface and Drainage in South-East England'. In this we summarized work begun while we were colleagues at King's College London and continued for nearly ten years during which, while teaching in different Universities, we were able to maintain full consultation and discussion and to take the field together on occasion.

The monograph was out of print by 1945. We have been encouraged to revise and reprint it in an extended form by the fact that it is still in request by students and others. Much of the material remains in the form in which it was originally presented with only minor alterations and the provision of additional maps. We have, however, extended our discussion on the drainage of the Weald and we have dealt also with the later stages of the Pleistocene development of the London Basin, and of the areas south of the Thames which lay beyond the glacial limit. This material will, we hope, be of interest to students of Pleistocene Geology, whether or not they agree with all our conclusions. We have necessarily taken account of the considerable volume of recent work in this field, and it has been a pleasant task to acknowledge, if on occasion also to criticize, the contributions of younger workers, notably F. K. Hare, B. W. Sparks, K. R. Sealy and Mrs. C. E. Sealy, which arose directly from our own studies, and extended or corrected conclusions we had reached. The latter chapters reflect also our indebtedness to two good friends of former years on the Weald Research Committee of the Geologists' Association, Dr. A. J. Bull and Mr. J. F. N. Green. Both have died in recent years and we have had cause greatly to regret our inability to seek their help in interpreting a very complex record which their own efforts did so much to clarify.

In the original monograph we were concerned to defend its geographical relevance, at least as a preparatory analysis without which no adequate understanding or intelligent description of South-East England could be contributed by the geographer. This view we should wish still strongly to maintain; we have stated it in our brief introduction and illustrated its bearing in our concluding chapter. The purely methodological issues involved have not, however, greatly concerned us in preparing the revision. The role and relations of Geomorphology have been sufficiently discussed elsewhere and should need to-day no special pleading or general apologetic. It is still true, as Geikie wrote, that 'the rocks and their origin form one subject of study, the history of their present scenery another'. The geomorphology of a region is a subject worthy of study in its own right; it has its own methods and reaches its own conclusions. It cannot be divorced from geology, upon the principles of which it rests and to which it forms a proper continuation and complement. Nor can there be the slightest doubt that it is a necessary preliminary to full geographical study. What we here present is a general essay on the geomorphology of a very important region: we hope that it embodies a contribution to both geology and geography and trust that colleagues and students in both subjects may find it of some use, despite its imperfections, while by criticism and further enquiry they correct these imperfections.

S.W.W.
London, 1955. D.L.L.

ACKNOWLEDGEMENTS

Structure, Surface and Drainage in South-east England was first published in 1939 under the auspices of the Institute of British Geographers and grateful acknowledgement is here made to the Council and Officers of the Institute for permission to republish the work in book-form.

At the time of first publication the authors expressed their fullest acknowledgement to the University of London and The Carnegie Trust for the Universities of Scotland who gave financial assistance in the production of the text and illustrations respectively, and they desire again to make that acknowledgement. Their thanks, as on the previous occasion, are also due to the Editors of the *Journal of Geomorphology* for the loan of the blocks for Figs. 16 and 21, and to the Council of the Geological Society of London for the loan of the block for Fig. 13 and to that of the Geologists Association in respect of the block for Fig. 1. The thanks of the authors are also due to Mr. R. S. Waters, now of the Department of Geography, University College of the South West, for substantial assistance in the preparation of the index of place names for this edition.

Acknowledgement is made also to the Controller of Her Majesty's Stationery Office for permission to incorporate in Fig. 32 Ordnance Survey material.

STRUCTURE, SURFACE AND DRAINAGE IN SOUTH-EAST ENGLAND

CHAPTER I

INTRODUCTION

We define South-East England for the purposes of the present work as the region lying south and east of the main Chalk escarpment between Dorset and the Wash. By whatever criteria it is judged and in whatever historical period it is viewed the area so delimited takes rank as one of the most important regions of Britain or indeed of the world. As such it must be regarded by the geographer, for it is essentially the metropolitan region of England which gave birth to London and conditioned in part the later phases of its life and growth. To the geologist also it offers much of interest. There has been, it is true, some tendency on the part of geologists to despise the relatively thin Tertiary deposits of the area, part of a wider disposition to concentrate on the problems of the older rocks. Yet it has been impossible to ignore at least the economic importance of the geology of the London district, nor can we readily forget a lifetime's labours in London geology of such former workers as William Whitaker and Sir Joseph Prestwich or the signal contribution made by William Topley's 'Geology of the Weald' to the general philosophy of both geology and geography.

In another and even more important respect the study of the area is indispensably cardinal. The shaping of the British landscape has been the work of Tertiary times, a period now indicated, by radioactive dating, as having a duration of some 65–70 millions of years. In this long interval the mountains were shaped, the valleys carved, and the coastlines developed to their present form. It is in this sense that Tertiary time in Britain means more for geomorphology than for stratigraphical geology. The story of sedimentation is scant, but the interval of time represented is vast, vast enough for the evolution of the whole British landscape as we know it. The history of British scenery is to be deciphered by the methods of geomorphology, the study of ancient peneplains or other erosion surfaces, of river profiles and river terraces, of drainage patterns and stages of coastline evolution. If we are to seek the chronology in these events we must find means of linking it with the chronology of strata, of past sea-bottoms with their deposits and included fossils. In the words of T. H. Huxley we must use 'sea reckoning for land time'. The only British region in which the two chronologies can be clearly brought into relationship is South-East England, for here we have

datable deposits of both Older and Newer Tertiary age, coupled with clear evidence of Tertiary folding and the record of erosion unarguably Tertiary in date. Our region thus serves as a comparator for the other regions of Britain and in high degree can claim the role of type area for British geomorphology. As such it was treated half a century ago by W. M. Davis and, though some of his conclusions must now be abandoned, the principle which he enunciated still stands, that the north and west of Britain must necessarily be seen and studied in the light of the south and east, since there alone Tertiary deposits of any considerable extent and thickness assist the reading of the record.

From this standpoint the following pages are offered as an essay in pure geomorphology and if the conclusions reached are sound they have implications far beyond the limits of the region here considered; they concern nothing less than the later stages in the geological record for the whole of Britain.

For the geographer it is hoped that they will have a further value. Considered on broad lines the structure and relief of South-East England appear deceptively simple. In essence we have a thick sheet of Chalk, warped and locally corrugated, of which the eroded edge forms a major escarpment. The higher parts of the Chalk sheet form upland down country or broad wooded ridges and plateaux. The low-lying tracts represent Tertiary sediments preserved in the major synclines which are margined or encircled by the dissected dip-slopes of the underlying Chalk. A diversified lowland of contrasted type occupies the heart of the Weald – a dissected anticlinorium – in which sands and clays emerging from beneath the Chalk are exposed. A great sheet of glacial drift covers the north-eastern part of the area introducing a further distinctive element in land type and land use. The major relief features are on longitudinal lines – divergent Chalk ridges radiating from Salisbury Plain. The drainage also shows certain longitudinal elements but includes many important transverse valleys. They cross, or have formerly crossed, the escarpments in many places thus creating the gaps, so prominent in the route pattern, which serve to divide the Chalk uplands into compartments.

So much may be gathered from any good small-scale map and so much is duly recorded in all elementary accounts of Britain. Against such a background a few of the leading facts in the geography of the region can be appreciated. Its major regional divisions, the London and Hampshire Basins, the Weald, 'Wessex' and East Anglia can be seen to be structurally determined; some major contrasts in the landscape are readily explained and the larger nodes in the settlement pattern appear in sites naturally related to the grain and relief of the land.

Yet closer scrutiny must at once convict this general picture of over-simplification. It leaves unexplained many physical qualities and features of the area not only significant in themselves but important in its role as a human environment. When we increase the scale of our map studies and still more if we examine the area in the field we encounter innumerable phenomena and effects unexplained by the broad structural picture. If our concern is with South-East England as a human region, these elements in its physical basis are of prime relevance. Many generations of human occupancy have 'developed' the terrain and differentiated its landscapes. It may be tempting and sometimes true to impute the landscape differences entirely to human factors. Much recent geographical writing tends to take this point of view, calling particular attention, with a satisfaction at times almost smug, to features in human distribution or economy which are not, in any evident sense, a reflex of physical conditions. Such distributions undoubtedly

exist; they are intrinsically 'sociological' rather than 'geographical' in the ordinary sense of the term and to perceive them is doubtless a safeguard against the cruder forms of geographical determinism. Yet the procedure too often adopted is hopelessly unscientific and indeed almost worthless intellectually. It is to dismiss the physical background in a simple and sweeping description, ignoring its complexities and overlooking many real differences within it and then to profess inability to see its relevance to human distributions. Such a method blindly begs the very question at issue. Only the closest study of 'physique' can equip us to decide which of its features are or were geographical determinants. Any such close comprehension of the terrain can be obtained in one way only, by tracing its evolution. Only so is it seen as a whole, with its parts and even its ultimate details harmoniously related one to another. Exactly the same method avails and is increasingly followed in the study of the humanized or cultural landscape. Its evolution is traced by the methods of historical geography; only so can it be fully comprehended. Despite the differences in the materials and procedures of the two studies there is a close methodological and philosophical kinship between geomorphology and historical geography, properly conceived. If our aim is to comprehend the landscape in the widest sense of that term it is indeed hardly too much to say that geomorphology is an important branch of historical geography. Whatever precise form of definition for his subject he favours, the geographer can hardly deny that he is concerned with the physical landscape, the cultural landscape and the relationships between them. But both have in fact evolved through a series of sequential stages and he can understand neither the one nor the other except in the light of its evolution. The purist may insist that the one evolution is a concern of geology, the other of a special branch of history. But this in no wise renders it less fruitful to consider them together. To such consideration modern geography is committed; its proper aim is to bring them into synoptic and stereoscopic review. It is true of course that the tempo differs markedly in the two cases; the geological evolution is virtually complete before the historical process starts. It nevertheless remains true that land differences derive from land history, both in physical and in human geography. To understand a region in its entirety requires that we first trace the origin, so that we can explain the form and pattern, of its hills, valleys and coasts. This is the primary enquiry, succeeded at once by another, the scrutiny of the sequence of human occupancy lying behind the economy as at present developed. It is to the first of these enquiries that we here seek to make a contribution. The concluding chapter gives some instances and indications of its relevance in the study of the human development of the region.

CHAPTER II

THE EARLIER STAGES OF STRUCTURAL GROWTH

(i) THE PALAEOZOIC FLOOR

We may first devote brief attention to the understructure and outer framework of the region. An invisible but ever present factor in its later structural development has been the Palaeozoic floor[1] which extends continuously beneath the area, emerging at the surface on its margins in Devonshire, Somerset, Gloucester and the Midland coalfields. It is buried beneath the cover of younger rocks and might seem to be almost literally beneath the notice of both geomorphologist and human

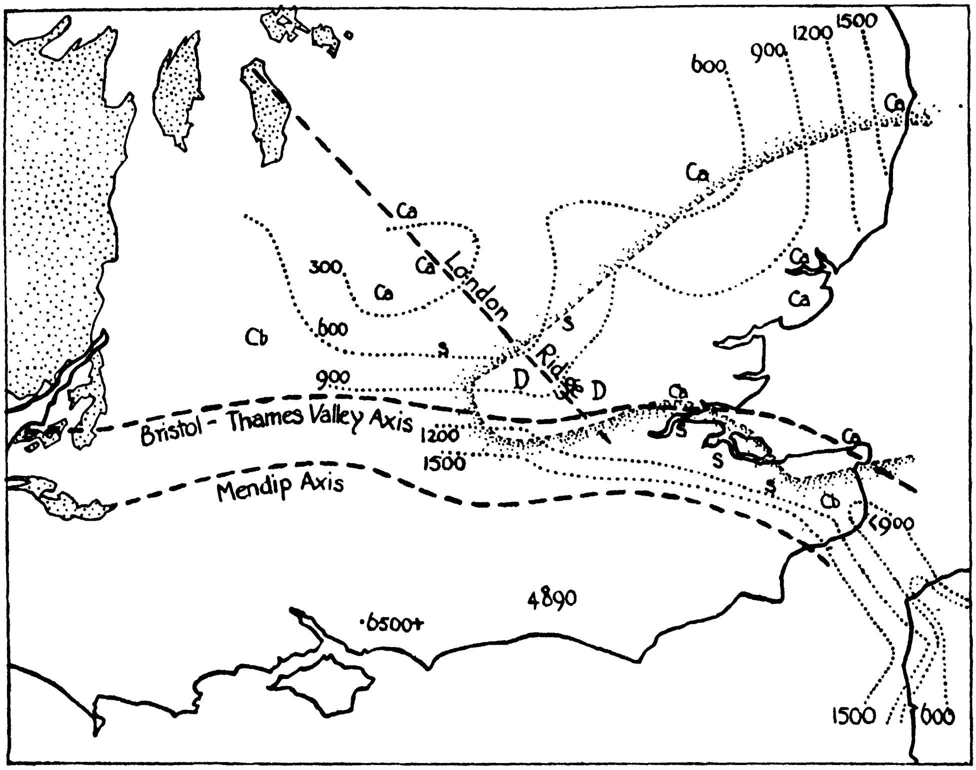


FIG. 1 – The Understructure of S.E. England. Present-day Palaeozoic outcrops stippled. Stippled zone in east is margin of Lower Greensand formation against the buried London Massif. Contours, at intervals of 300 feet (and isolated figures near South Coast), show depths from O.D. to Palaeozoic surface.

Ca = Cambrian S = Silurian D = Devonian Cb = Carboniferous

geographer. Such is far from the case. Although the Upper Cretaceous rocks once extended continuously across the region, the older Mesozoic formations are confined to major hollows in the floor. This is itself a fact of importance, but it may also be shown that the form and structure of the floor have influenced the deformation of the cover rocks and that many ancestral traits of form and structure are, in effect, inherited through the cover from the buried undermass.[2]

In several respects an important distinction can be drawn between the areas of the floor lying respectively north and south of the line of the Lower Thames valley. Thus north of the Thames the floor is at shallow depth, sloping gently from North Bucks, where it is only 450 feet below the surface, towards the London district where it is reached about 1,000 feet below the surface. There are moreover considerable undulations in the floor, of which one is of particular importance. A low ridge of N.W–.S.E. trend maintains the floor at a depth less than 1,000 feet below O.D. over an area of which the axis is roughly the line of Watling Street. We shall term this feature the 'London ridge'. A complementary depression trends diagonally across northern Essex; it is chiefly evidenced by the boring at Saffron Walden which failed to reach the floor at a depth of 804 feet below O.D. (Fig. 1).

South of the Thames the floor plunges relatively steeply, and beneath the Central and Southern Weald it is roughly a mile below the surface (Fig. 2).

Again, north of the Thames the available evidence indicates a great area of pre-Devonian rocks and it is believed that we have here an analogue of the Brabant massif of Belgium. South of the Thames it is probable that the floor is the continuation of the Devono-Carboniferous tracts of Devonshire and the Ardennes.

In no part of the floor, except in and around the Kent coalfield, is the direct evidence of borings sufficient to give a picture of the structure of the older rocks. We are forced to argue from the analogy of the emergent tracts of the floor, supporting our reasoning where possible by the records of borings and indirect evidence. There can, however, be little doubt that important differences of structure exist between the areas north and south of the Lower Thames. Comparison with the emergent areas in Belgium, and in Devon and Cornwall, suggests that the southern area is traversed by powerful folds of generally E.–W. trend. North of the Thames thereis neither direct evidence nor indirect suggestion of E.–W. folding in the floor. The projection of the floor structures of the Midlands towards London suggests rather that N.W.–S.E. elements are dominant; in particular we might expect to find the continuations of the ancient axes of uplift marked by Charnwood Forest and the Nuneaton ridge (Fig. 3). There is considerable evidence that these axes are in fact so continued, and the 'London ridge' probably reflects late movements along the latter.

Despite the instance just quoted, we should anticipate no close general relation between the form and structure of the floor, for it is essentially a warped peneplain bevelling the structures of its constituent rocks. Nevertheless, both form and structure combine to emphasize the magnitude of the contrast in underground conditions which takes effect at the line of the Lower Thames valley. Structurally indeed this line is probably the continuation of one of the major tectonic boundaries of Europe, that which separates the *Palaeo-Europe* and *Meso-Europe* of Stille.[3] In the latter, the E.–W. Armorican folds advance wave-like towards the earlier folded and compacted Palaeo-Europe and break in thrusts upon its edge. This phenomenon is well seen in the Franco-Belgian coalfield and again in Somerset,

South Wales and southern Ireland. There is good reason for thinking that it would be visible beneath the London area if the cover could be removed (Fig. 3.).

The importance of the under-structure in the morphological study of South-East England lies in the relationship between the surface structures and those beneath. Following Godwin Austen's triumphant inferences of 1856[4] which led to the discovery of the Kent coalfield, it was confidently assumed that the principle of 'posthumous folding' was widely applicable and that the structure of the floor was perpetuated in that of the cover. The precise equivalence of surface and sub-surface anticlines could not in fact be proved, but evidence of long-continued instability in the former, showing itself in the thickness and lithological character of strata, was accepted as evidence of the recurrent unrest of buried structures. In general the principle is now universally accepted by geologists, but it is far from certain that it can be applied with equal validity in all parts of our area. North of the Thames, where the cover is thin, the conditions may be fairly likened to those of a skin of plasticene resting on the blocks of a parquet floor, and when the latter moved anew as a result of later stresses, the skin no doubt accommodated itself to the movements of the undermass. It is much less likely that the powerful folds of the Central Weald and the South Coast zone bear any close relation to folds in the floor, for it is difficult to conceive that the latter have been transmitted through

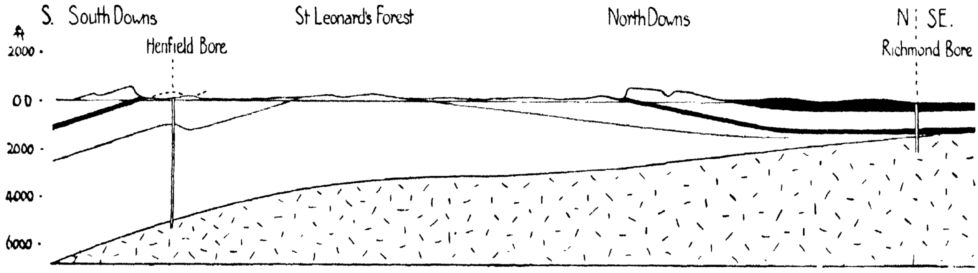


FIG. 2 – Scale Section to illustrate the Understructure of the Weald and London Basin. The strata shown are as follows: Tertiary Beds in the London Basin, black. Chalk, white. Upper Greensand and Gault, black. Weald Clay

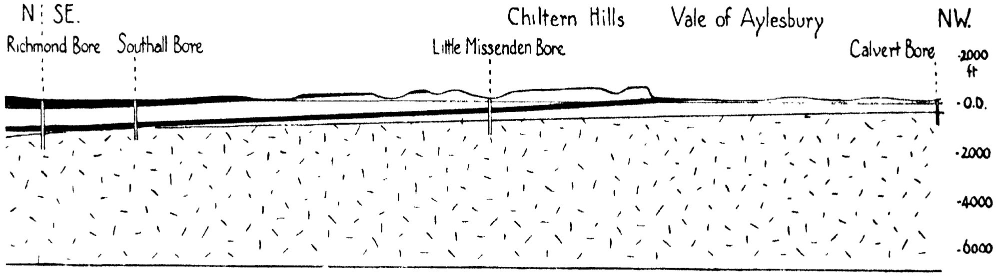
covering sediments a mile thick. The Thames valley and the northern flank of the Weald lie in an intermediate region where the floor is at moderate depth and here there is evidence that the E.–W. folding of the floor is legible, by virtue of renewed movements, in surface structures. There is impressive evidence of spasmodic uplift along the line of the Lower Thames valley during Upper Cretaceous times and a series of aligned anticlinal structures is traceable at the present surface. We regard these evidences as witnessing the continued instability of what is probably the most northerly of the main Armorican anticlines – the continuation of the Cardiff-Bristol axis. Similarly there is some warrant for regarding the anticlinal line of Pewsey-Kingsclere-Peasemarsh, etc. (p. 21), as marking the buried continuation of the Mendip axis. South of the Mendip line, there is likely to be little more than a general coincidence in direction between floor and cover structures.[5]

(ii) THE ACCUMULATION OF THE COVER

The present attitude of the floor and particularly that part of it north of London does not completely indicate its role during the accumulation of the cover, for it has been modified by the movements which have deformed both cover and undermass

together. During a great part of Mesozoic times the area of older rocks beneath the London area and East Anglia projected as a 'massif' above the tracts lying to the north and south of it. The floor in the latter regions was depressed in deep troughs concurrently with the accumulation of great thicknesses of sediment, the deposits of the Triassic deserts and the Jurassic seas. The intervening massif was initially part of a considerable mountain range, but it was subject to long-continued sub-aerial destruction and was base-levelled before the end of Jurassic times. It is probable that part of the Upper Jurassic rocks were deposited over all or most of the former upland area and the peneplain surface was thus trimmed by marine erosion. Thereafter the London massif was subject at least to local uplift and most of the Jurassic cover was stripped from it. It was at this time that the earliest recognizable movements along the line of the London ridge occurred. The sedimentary investment of the massif was resumed in Lower Cretaceous times, and at the beginning of Upper Cretaceous times the sea extended completely across it and it was finally buried beneath the Gault.

It was formerly supposed, following the work of Lamplugh,[6] that the southern trough terminated essentially near the Sussex coast. This conclusion was contested by J. W. Evans[7] who pointed out that the thick sedimentary pile beneath the Weald was probably continuous with that beneath the Paris Basin. Recent



(present only in the Weald), white. Remaining Mesozoic strata, white. Folded Devonian and older rocks of the London Massif, stippled. Length of section 86 miles. Vertical scale 5.28 times horizontal.

borings for oil in Sussex and Hants have gone far to confirm this view. The northern trough was shallower and less extensive, extending essentially between the London massif and Wales. Just as the Sub-Wealden sediments thin northwards towards London, so Jurassic rocks 3,000 feet thick in the Cotswold Hills are only 1,000 feet thick in North Bucks (Calvert) and have thinned out completely before Ware is reached. While, however, the Wealden-Parisian trough remains essentially in its original attitude, the sedimentary cover of the South Midland region has been tilted as a whole towards the south-east and the western taper-edge of the former sedimentary filling, abutting on the margin of the Welsh massif, has been entirely removed by denudation.

With the burial of the London massif beneath the Gault, its long-continued dominance as an upstanding element was virtually ended, and during the accumulation of the Chalk we can trace the faint beginnings of the present major structural plan – essentially an inversion of the former condition. The several Upper Cretaceous stages thicken in areas of contemporary subsidence and are thinner in the intervening tracts of uplift.[1] During Albian (Gault and Upper Greensand)

times both the northern and southern troughs show evidence of continued slight subsidence. In the succeeding Cenomanian (Lower Chalk) stage, we obtain perhaps the first manifestation of uplift over the Wealden area, for towards this area the thicknesses diminish. Turonian (Middle Chalk) times witnessed in some sense a reversion to the former state of things; subsidence temporarily set in anew over the Wealden area, the greatest thicknesses being recorded on its southern margin. In all three stages there is evidence of uplift, expressed as relatively small thicknesses, along the Thames valley zone.

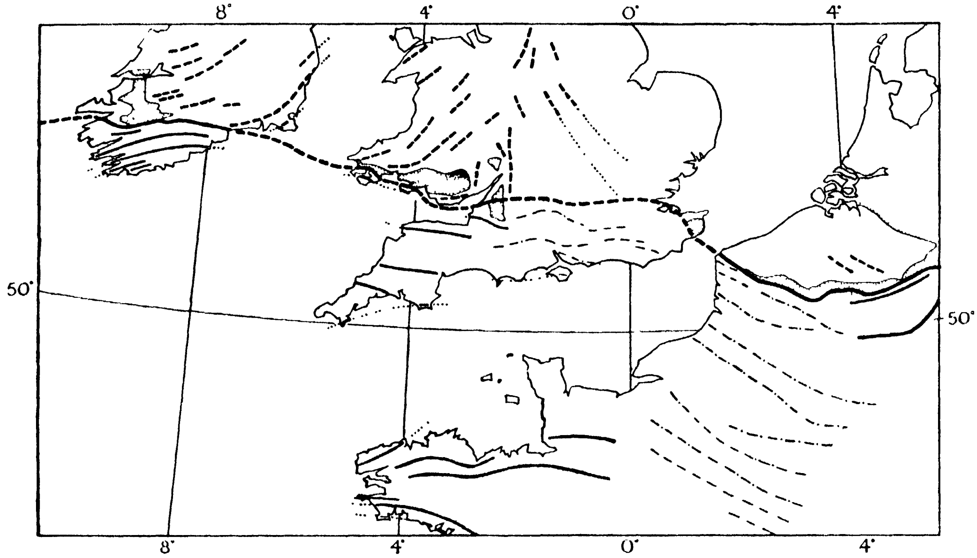


FIG. 3 – The boundary of Meso-Europe and some principal fold lines in the British region. Fold axes in Palaeo-Europe, broken lines. Fold axes in Meso-Europe, full lines. Inferred continuations of both the above, dotted lines. Fold axes in the Neozoic cover, chain-dotted lines. Coalfields associated with the boundary, stippled.

The Upper Chalk (Senonian) stage does not yield much explicit information as to contemporary movements, for before the accumulation of the earliest Tertiary deposits, the area was irregularly upheaved and subjected to long-continued destruction as a land-surface. Variations of thickness thus reveal the combined effects of contemporaneous and later (pre-Tertiary) movements, and the latter, in general, have masked the former. It is clear that differential movements were in progress during Senonian times and they may well have foreshadowed in some detail the pre-Tertiary movements. These we must consider at greater length for they rank as one of the important formative phases in the structure of the region and have left visible results in the present landscape.

(iii) THE PRE-TERTIARY MOVEMENTS AND EROSION CYCLE

The shallowing sea of the later stages of Senonian times signifies the beginning of a regional uplift which culminated in widespread emergence of the sea-bottom. Though, in the broad view, this uplift was of a relatively gentle and uniform character, there was sufficient irregular upwarping to lead to the removal of

hundreds of feet of Chalk from the crests of arches during the succeeding lengthy phase of erosion. The sub-Eocene Chalk surface is remarkably flat and uniform; it bevels the folds produced by the pre-Tertiary movements and is evidently a peneplain locally trimmed by the waves of the Eocene sea.

The structure of the sub-Eocene surface can be rendered clear in two ways, viz. by considering the thickness of the Upper Chalk as a whole, and by mapping the distribution of its several divisions over the surface.

The Upper Chalk attains thicknesses exceeding 1,000 feet in the southern part of the Hampshire Basin, but thins northward towards the Wealden uplift. On the further side of the latter is another tract of thickening which may be taken to indicate, in some sense, the pre-Eocene London Basin. There are evidences also of more localized movement. A line of pronounced upwarping marked by low thicknesses passes from N.W.–S.E. (Watford–Streatham) across the London area. In this great cross-warp, which effectively divides the London Basin in two, we see one of the ancestral traits of the region, for the uplift is co-axial with the 'London ridge' in the buried floor, and similar movement occurred also in later times. Localized movements of uplift in the Thames valley zone also took place in pre-Tertiary times.

In considering the distribution of the sub-divisions of the Upper Chalk, we may here rest content with the two-fold division, proposed by Jukes-Browne, into Micraster Chalk and Belemnite Chalk.* In the Hampshire Basin, the Eocene base rests everywhere on the Belemnite Chalk and large outliers of the latter occur in the country to the north (Fig. 4). In the London Basin, a thin selvage of *Marsupites* Chalk margins the southern side from the western extremity as far east as Orpington. Thence eastwards surface outcrops are not resumed till we reach East Kent. On the northern side of the London Basin, the Belemnite Chalk appears in the west near Hungerford, but is thereafter not seen in contact with the Eocene base till East Anglia is reached. Figure 4 supplements the available geological maps of South-East England in directing attention to a salient feature of the morphology of the Chalk areas. On the north of the Hampshire Basin and throughout Sussex, the Belemnite Chalk gives rise to a second or outer Chalk escarpment, the more resistant beds of the *quadratus* zone projecting above weaker marls in the zone of *Marsupites*. No similar feature is present in the North Downs, where little Chalk higher than the *Marsupites* zone occurs, and it is absent too in the Chiltern Hills. The reappearance of the higher division in East Anglia is hidden beneath glacial drift.

The distribution of the Belemnite Chalk around the London Basin enforces the conclusion drawn from a study of thickness, emphasizing clearly the importance of the great cross-warp. Further, it is implicit in Fig. 4 that the Eocene base oversteps the Chalk divisions as traced towards the 'cross-warp' and also as traced outwards from the axis of the Basin. In Wessex less complicated relations are revealed; there is evidence of a more or less regular overstep by the Eocene base. The pre-Tertiary movements seem here to have produced a fairly regular southerly tilt uncomplicated by pronounced minor folding. We have seen, however, that there was uplift of the Wealden tract complementary to the depression of the

* The former comprises the zones of *Micraster cor-testudinarium* and *Micraster cor-anguinum*, and the latter the topmost zones from that of *Marsupites testudinarius* upwards.

Tertiary basin areas. It thus appears that the periclinal bulging over the Weald, perhaps initiated in Cenomanian times, was strongly enhanced by the pre-Tertiary movements.

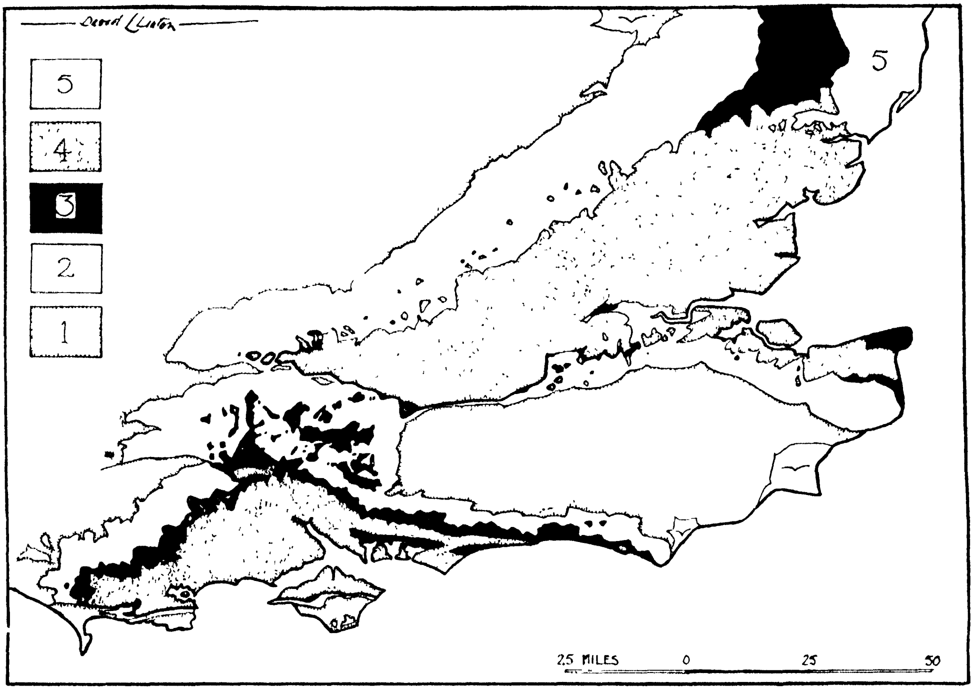


FIG. 4 – The Eocene overstep of the Chalk zones.

1. Pre-Cenomanian. 2. Cenomanian, Turonian and Lower Senonian Zones. 3. Upper Senonian Zones. 4. Eocene and Oligocene. 5. Pliocene.

The proved overstep of the Eocene base is a fact of prime importance in interpreting the later morphological history of the area. On the south of the London Basin the rate of overstep is over 30 feet per mile; on the north it is rather less, roughly 25 feet per mile. A continuance of these rates would lead to the complete overstep of the Chalk in distances of 10–15 and 18–20 miles respectively. We know, indeed, that the Chalk cover was locally breached in Eocene times, for debris from horizons below the Chalk found its way into the Eocene deposits. The available data do not warrant the assumption that the Chalk was completely overstepped over wide areas, but it is at least certain that large thicknesses of Chalk were removed from the Wealden and South Midland regions in pre-Tertiary times and the amount of erosional work to be assigned to later cycles of denudation is thus very considerably reduced.

(iv) THE EOCENE AND OLIGOCENE GROWTH STAGES

It is clear therefore that South-East England had taken on a strong semblance of its present structural plan as a result of the pre-Eocene movements, but it was still separated by an interval of many millions of years, from the main tectonic

crisis, the 'Alpine Storm', to which its more obvious features of form and structure are clearly due. We can trace the tectonic history of this interval only with the help of such measureable facts as are afforded by the Eocene and Oligocene deposits. Our evidence is limited by the fact that these deposits are restricted in extent; only where they are present can we hope to trace the further evolution of the crust-ripples which figured in earlier movements. What happened in the major upwarped areas between the Eocene depressions, must for ever remain a subject for surmise, or, at best, for argument by analogy.

The structural evolution of the London Basin during Eocene times may be traced by plotting the thickness of the chief formations, and fixing the position of coastlines separating marine and continental deposits during the successive phases of the period.[8] The Basin as a whole grew spasmodically, the periods of deepening ushering in the several marine transgressions. It is also clear that the thickness and lithology of the several formations reflected posthumous movements along the Thames valley axis, the main transverse axis (corresponding to the London ridge), various N.–S. lines of monoclinal flexure believed to correspond with great transverse fractures in the Palaeozoic floor, as well as along certain other minor axes of instability. The Hampshire Basin reveals a closely analogous Eocene record.[1]

It may be well to emphasize that the existing synclinal basins are not simply basins of deposition like many of the Newer Tertiary Basins of Western Europe. The Eocene deposits extended well beyond their present outcrops. There is little doubt that some part of the Eocene cover extended across the Chalk of the Wessex area and similarly it has been removed from wide tracts on the flanks of the Weald. Nevertheless, it is believed that the Central Wealden area projected as an island above the Eocene sea and both the London and the Hampshire Basins were marked out as subsiding tracts within the general area of sedimentation. It is therefore true to say that the general geography of the Eocene period conformed with the earlier structural tendencies we have traced, and also that it foreshadowed to a significant extent the existing structural arrangement.

From the local standpoint, the Oligocene beds of Hampshire appear as an almost insignificant addendum to the Eocene record. Their area of outcrop is very restricted and it is doubtful if they ever extended far beyond their present limits. They reflect, indeed, a phase of widespread if gentle, uplift and warping, which, in detail, may well have been premonitory of the more violent movements which followed in Oligo-Miocene times. It is true that the Eocene land surfaces surrounding the basins of deposition must have been far advanced towards peneplanation, so that small changes of level would produce large shifts of strandline, and it has generally been supposed that a more or less uniform uplift of the whole region took place, excluding the sea from the London Basin and from all save the central tracts of the Hampshire Basin. Nevertheless, it is to be noted that the only positive tectonic evidence afforded by the Oligocene strata is of renewed downwarping of the Hampshire Basin which twice gave access to the sea. With the tectonic record of Eocene times in mind, we can hardly doubt, therefore, that similar localized movement, both of downwarping and of elevation, occurred elsewhere in the area, as an integral part of the general phase of uplift. It seems probable, indeed, that the great Oligo-Miocene anticlines began their rise during the early part of the Oligocene period.

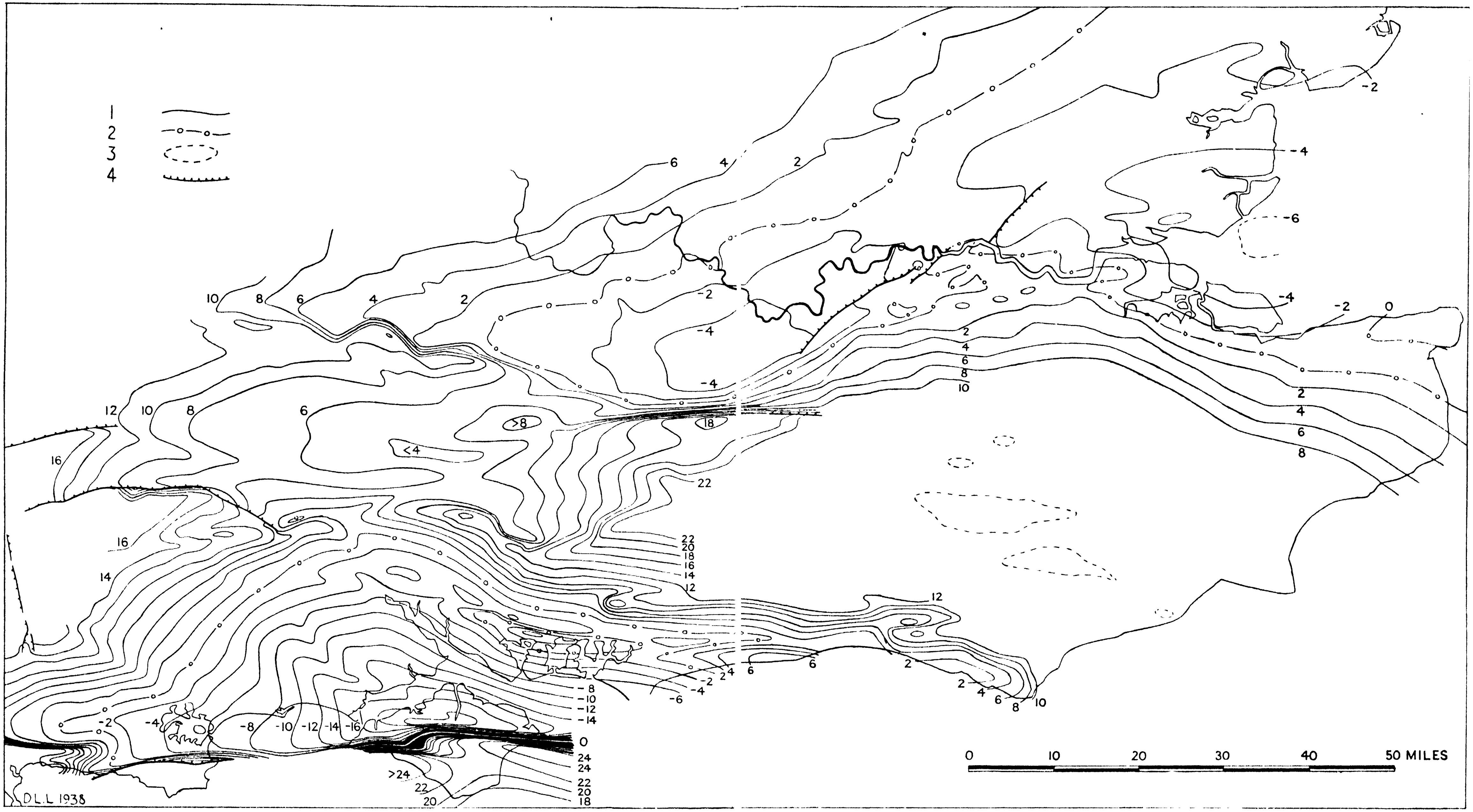


FIG. 5 – The Post-Alpine relief of S.E. England as indicated by the contours of the sub-Eocene surface. 1. Contours of the sub-Eocene surface at 200-foot intervals. 2. Sea-level contour. 3. Culminating areas in the Central Weald in which the altitude of the sub-Eocene surface may have exceeded 3,000 feet. 4. Some important fault lines.

CHAPTER III

THE ALPINE EARTH MOVEMENTS

(i) THE AGE OF THE ALPINE STRUCTURES

We come now to the major formative phase in the structural evolution of South-East England, that of the Oligo-Miocene or Mid-Tertiary movements, aptly characterized by the late Professor Grenville Cole as 'the outer ripples of the Alpine storm'. It was, of course, these movements, in essence, which imposed the existing major structures on the region. In some cases they augmented, emphasized or brought to completion structures which had been growing intermittently for a long earlier period, but to a considerable extent they also imposed upon the region important new lineaments, of whose earlier growth we can discern hardly any indications.

The age of the movements judged by local stratigraphical evidence is post-Middle Oligocene and pre-Middle Pliocene, for the Hampstead Beds (Middle Oligocene) are involved in the folding in the Isle of Wight, while Pliocene deposits, regarded as equivalent in age to the Red Crag of East Anglia, rest upon a surface bevelled across the folds in the London Basin. By other arguments we can define the date of folding more closely. It is, for instance, certain that a base-levelled surface older than that which carries the Pliocene deposits of the London Basin had been extensively developed across the folded tracts, and this surface evidently required much, if not most, of the Miocene period for its production. Probably, therefore, we should place the folding episode in late Oligocene or, at latest, in early Miocene times. We incline to the view that the differential movements of earlier Oligocene times, which first restricted the sea to the Hampshire region and later excluded it altogether, were in fact the beginnings of growth along the principal 'alpine' fold axes, and that the process was continued spasmodically, with increasing vigour and growing complexity, toward a climax about the end of Oligocene times. Thereafter the intensity of the folding stresses gradually diminished, and Miocene times must have witnessed a long period of great crustal stability which permitted the development of a widespread peneplain across the whole folded region.

(ii) THE CHARACTER OF THE ALPINE STRUCTURES

The most obvious result of the Alpine folding in the region, as judged from a small-scale map, is that it completed the major structures. It is true that in later times, on at least one occasion, (p. 54) slight renewed deepening of the London Basin may have occurred. In all essence, however, the Alpine movements were responsible for the present disposition of the strata of South-East England. The main synclines were deepened, so as to take on a strong semblance of their present general form and relations, while the anticlines were raised so high that subsequent denudation has, in general, completely removed their crests. So far, indeed, as the major structures are concerned, the Alpine movements represented the culmination of

age-long tendencies. The earlier (Jurassic and Cretaceous) aspect of the region had been wholly different, with the London platform projecting as a positive element above the surrounding troughs. The reverse tendency set in, as we have seen, in Cenomanian times. In Turonian times there was a temporary reversion to the 'Jurassic' aspect, but the post-Senonian movements finally established the main lines of the 'Tertiary' ground plan, which developed steadily during Eocene times to its Oligo-Miocene consummation.

The major Alpine structures are not simple crests and troughs, but complex units built of minor elements. The Weald and the Wessex Chalk area combine to form an *anticlinorium* embracing some half-dozen separate lines of anticlinal uplift and to a somewhat smaller degree the London and Hampshire Basins can claim rank as *synclinoria*, being subdivided by minor anticlinal lines. It is these longitudinal folds, complicating the major anticlinorial and synclinorial areas, that form the especially characteristic feature of the Oligo-Miocene folding, and, indeed, it is commonly only these features that are referred to when the terms 'Mid-Tertiary' or 'Alpine' folds are employed. They are, however, not the only, nor necessarily the chief results of the Oligo-Miocene episode and we have no reason to believe that they were wholly produced by it. Like the larger and broader structures whose earlier evolution we have already traced, they must have possessed some antecedents and have grown from small beginnings in earlier periods. But while we may admit the existence of a general tendency for the Alpine flexures to arise along the lines of their more feebly outlined predecessors, we must also observe that the strength of the tendency varies very markedly in the different parts of the region. In Wessex and the Weald the Alpine structures are strong and dominant features, while their earlier representatives are, in general, obscure or unknown. By contrast, the Alpine structures that complicate the London Basin are comparatively insignificant and not markedly larger than the earlier folds, of which, in nearly all cases, they appear as the natural successors.

The cause of these contrasts is not far to seek, since it clearly resides in the varying depth of the Palaeozoic floor and in the relative ease with which the structures of the latter could perpetuate themselves through the sedimentary cover. Evidently we shall find it necessary and convenient to describe the Alpine structures of South-East England under two main regional headings:

(a) The main belt of Alpine folding comprising the Weald and Wessex, forming natural tectonic continuations of each other, but contrasted in their general structural attitude and the extent of denudation which they have sustained.

(b) The London Basin, the region of gentle 'foreland' flexuring under the control of the structures of the ancient undermass.

The subdivision is not entirely clean-cut, for the northernmost of the main Alpine axes lies within the London Basin along the line of the Thames valley. Here we see an indication that both the form and the structure of the undermass have their due effect in the structures of the cover, for as we noted earlier (pp. 5 and 8) this line marks the structural boundary between Palaeo- and Meso-Europe. It is to be noted also that the London and Hampshire Basins, though superficially similar, stand in very different relationship to the buried Palaeozoic surface which supports the cover rocks. The latter is included completely within the main zone of folding while the former lies, for the greater part, beyond this zone.

This contrast between the structures of the London Basin and those of the Wessex-Wealden zone is further emphasized by the difference in their ground-plan. In general it is true to say that in areas of pronounced folding the fold axes cannot be represented by straight or continuous lines. Maps which attempt such a form of portrayal are little better than the old crude 'caterpillar' maps of relief. Individual folds are short and arcuate in form. They may be grouped in zones, but not forced into simple alignment. Such, as we shall see, is the type of ground-plan revealed in Wessex and the Weald. But in the London Basin arcuate fold plans are conspicuously absent; the structural pattern is a more or less rectangular network. The contrast is one between competent and incompetent folds, the former essentially self-subsisting structures, the latter trifling surface readjustments in harmony with more fundamental movements beneath.

(iii) THE MAIN BELT OF FOLDING

a. *Wessex*

The leading structural features of the main fold belt in Wessex and the Weald are portrayed in Figs, 5, 6, 7 and 8. For Wessex we are able to present a quantitative picture of the folding in the form of a contoured map of the sub-Eocene surface (Fig. 5). For the construction of such a map it is essential to select a datum plane occupying a more or less central or median position in the folded pile of rocks. Since, in such cases, the folds are rarely symmetrical, i.e. their axial planes are inclined, and moreover, the constituent strata vary somewhat in thickness over the area, contoured structural maps at different levels are not identical, and the level for treatment must be selected with reference to the problem in hand, and to the data available for reconstruction. For our present purpose the sub-Eocene surface offers evident advantages. Its varying height above sea-level can be obtained over considerable distances along the north side of the Hampshire Basin and the south side of the London Basin. In the central tracts its position can be inferred without serious error, from a knowledge of the distribution of the Chalk zones of the present surface, and of the probable thickness of the eroded part of the Upper Chalk. Within the Hampshire and London Basins its position underground is known in numerous wells and we can link these records by contouring the base of some higher Tertiary surface and making allowance for the thickness of the intervening sediments. Figure 6, which shows the chief fold axes, affords a simplified key to the contoured map of the folding.

The Wessex area is traversed by three main groups of anticlinal axes, which we shall distinguish as the southern, central and northern structural zones. On a small-scale geological map their general position is indicated by the well-known flexures of the Isle of Purbeck and the Isle of Wight in the south, and by the two chief re-entrants in the western Chalk edge, the Vales of Wardour and Pewsey. Between the three zones of uplift lie two structural depressions of very unequal size and depth, the Hampshire Basin and the 'Andover depression' which extends westwards beneath Salisbury Plain. So much is readily gathered from the distribution of the main geological outcrops, but the facts recorded in Fig. 6 enable us to extend and to qualify this simple generalization.

The southern zone comprises essentially the Chaldon, Purbeck, Brixton and Sandown anticlines trending E.–W., but disposed *en echelon*. All are markedly asymmetrical with nearly vertical northern limbs partly replaced in the Purbeck and Chaldon folds by high angle thrust-planes.[9] Along the northern front of the

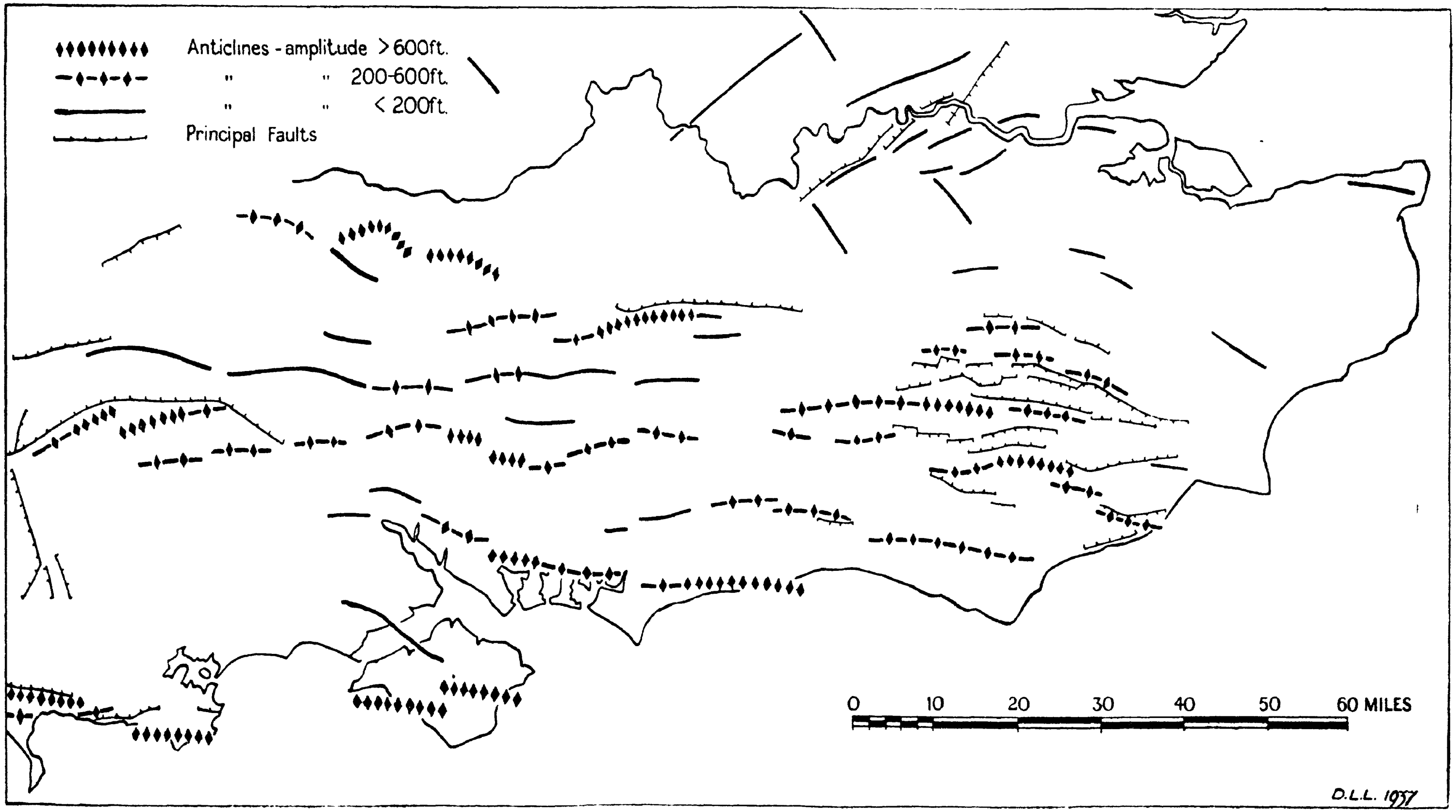
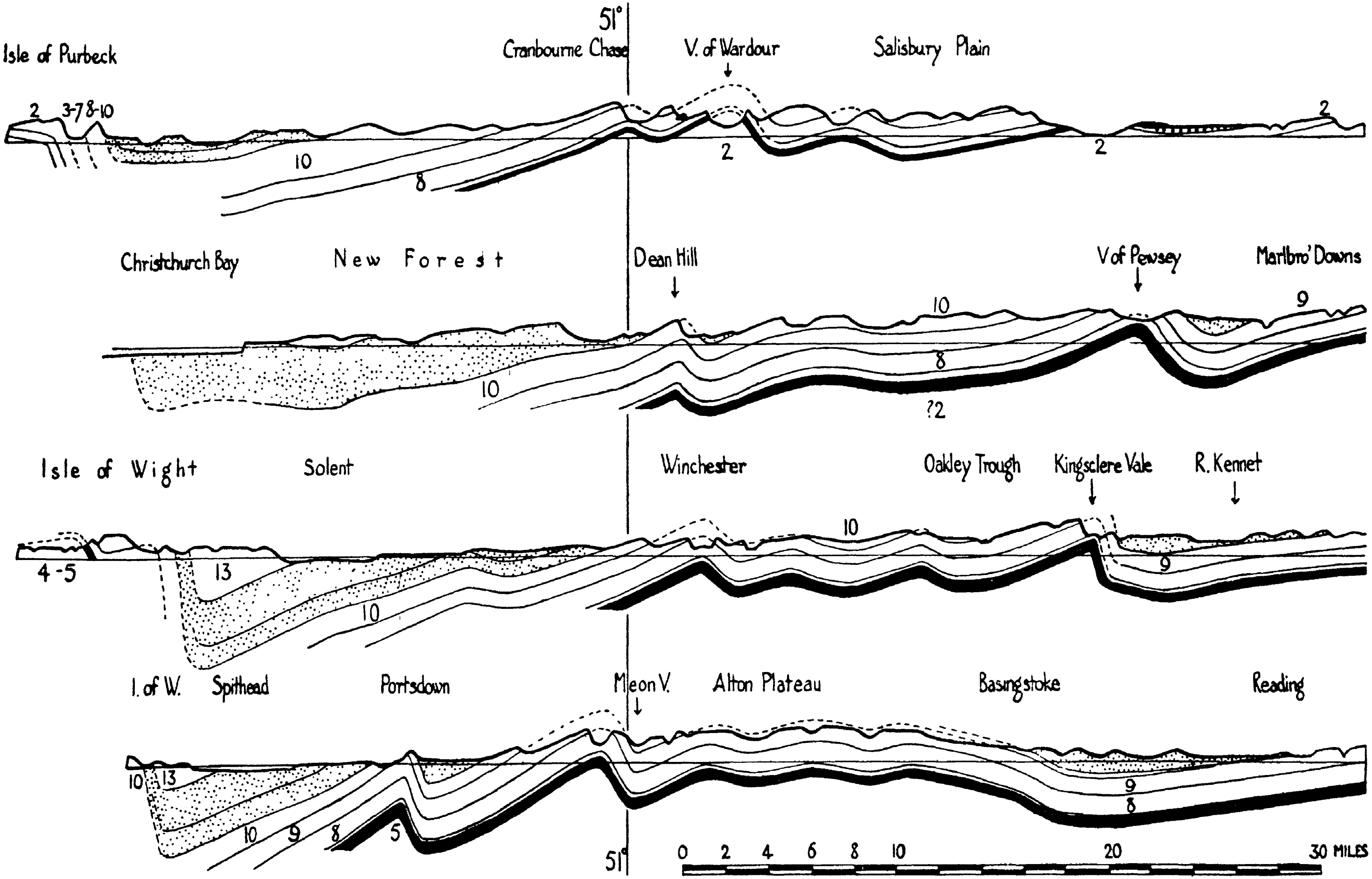


FIG. 6 – The principal fold and fault lines of S.E. England.


51°
Isle of Purbeck
Cranbourne Chase
V. of Wardour
Salisbury Plain
2
3-7
8-10
10
8
2
2
2
Christchurch Bay
New Forest
Dean Hill
V of Pewsey
Marlbro' Downs
10
9
8
10
?2
Isle of Wight
Solent
Winchester
Oakley Trough
Kingsclere Vale
R. Kennet
10
4-5
13
9
10
I. of W.
Spithead
Portsdown
Meon V.
Alton Plateau
Basingstoke
Reading
10
13
9
8
10
9
8
5
51°
0
2
4
6
8
10
20
30 MILES

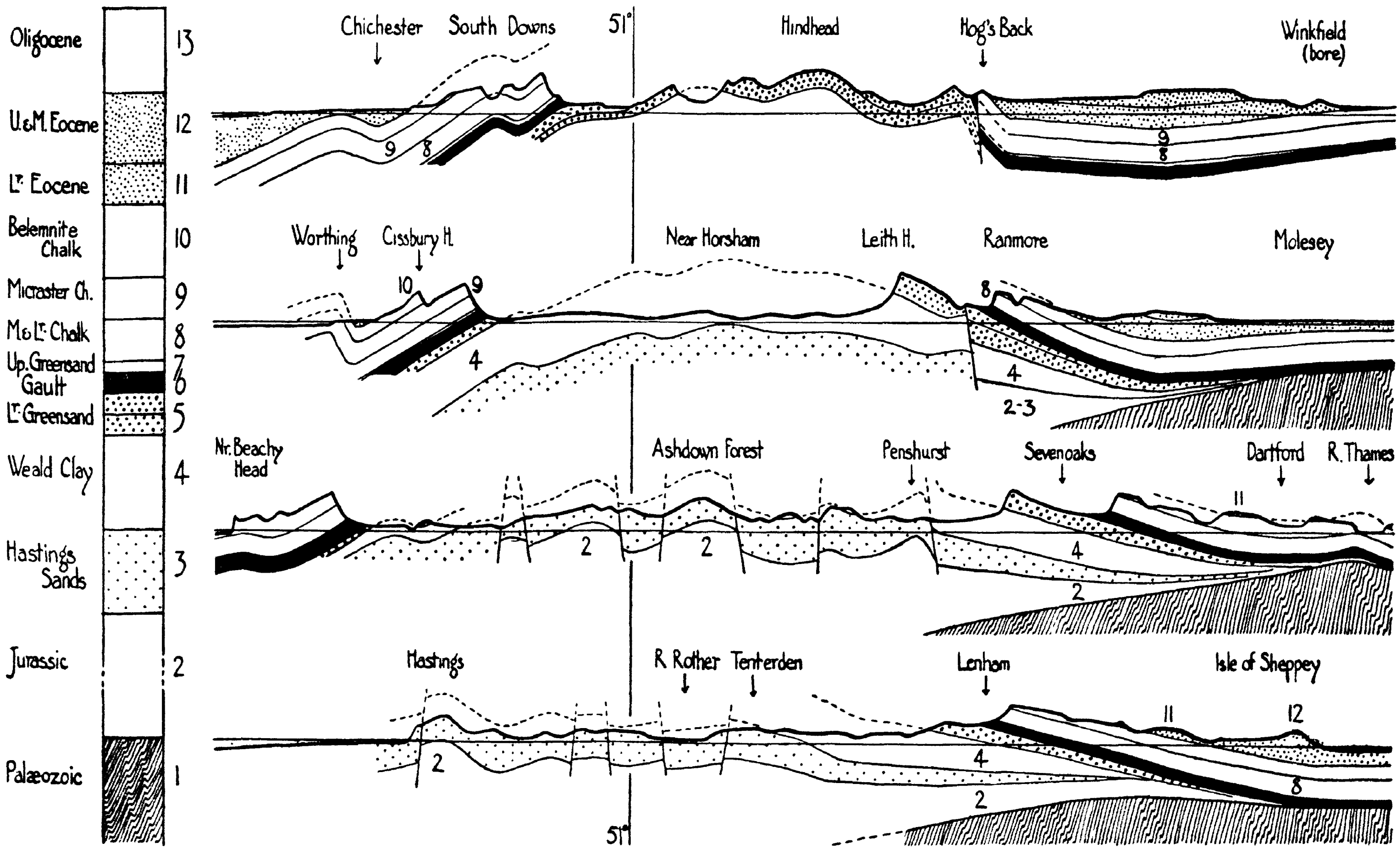


FIG. 7 – Serial scale sections across Wessex and the Weald.

zone and tending to converge eastwards on the main line of folding are gentle flexures such as those of Milton Abbas and Porchfield, trending W.N.W.–E.S.E. The roughly aligned flexures of Cadnam, Swaythling, Portsdown and Worthing swing down on a parallel line; they increase in intensity eastwards and become as strong as the folds of the central group with which they form a link.

At its western end, the central zone comprises the Warminster and Wardour anticlines, each faulted along its northern flank (with northerly downthrow), while to the south are the nearly aligned gentler flexures of Bower Chalke and Knighton Hill. Between Salisbury and Winchester the zone is more simply constituted, showing two main anticlinal lines, those of Warminster-Stockbridge and Dean Hill-Winchester, with the complementary synclines of Micheldever and Alderbury, the latter retaining its Eocene filling. On approaching the western limits of the Weald, however, the Warnford and East Meon anticlines set in southward of the continuation of the Warminster and Winchester lines, and reach a much greater tectonic elevation. The central zone is thus markedly broadened, while between its southern limit and the Portsdown line occurs the rather isolated E.–W. flexure of the Dean valley, north of Chichester.

In the west, the main folds of the northern group trend as a whole W.N.W.–E.S.E., and comprise the Pewsey fold and the arcuate periclines of Ham and Kingsclere. The Heydown Hill fold is a southern offshoot from the main line converging on the folds of the central zone. The Farleigh Wallop anticline passes obliquely across the ends of the Kingsclere and Heydown Hill folds trending W.S.W.–E.N.E., and from some points of view might better be regarded as part of a northward expansion of the central zone. Southwards of its line, the Peasemarsh fold sets in, with the Hog's Back thrust along its northern flank.

Taking a general view of the map, we note a contrast in the regions on either side of the line of the river Test. Westwards the three main anticlinal zones are clearly separated by tracts of little or no folding, (1) in the country around and to the south of Cranborne Chase, and (2) in Salisbury Plain. Eastwards the folding is more generally distributed, largely owing to the expansion or encroachment of the central zone towards its neighbours. In the west a traverse from the coast to the Newbury-Bath road crosses five or six anticlinal axes. In the east, if we include the southern axes, whose courses are partly beneath the sea, eight or nine anticlinal crests are crossed in a similar distance (compare Figs. 6 and 7).

b. *The Weald*

It is unfortunate that the method of the contoured datum plane which we have used for the Wessex region cannot be extended to give similar quantitative information regarding the structure of the Weald. At best we can only attempt such representation for parts of the area, and we cannot use the fragments thus mapped in any larger synthesis. We can trace the datum plane already employed, viz. the sub-Eocene surface, eastward from Wessex into the two flanking regions of the North and South Downs with some degree of assurance (Fig. 5). Further, we have found it possible to construct a map on similar lines for the relatively small tract of the Central Weald using the basal plane of the Weald Clay as our datum (Fig. 8). But we cannot fairly use this material to extend our mapping of the sub-Eocene surface into the central area. To do so would involve the addition of the very doubtfully computed thicknesses of all the formations, up to and including the Chalk, to the altitudes shown upon our contour map. Even could this be done

the results would still be falsified by the severe but indeterminate denudation of the Wealden crest in pre-Eocene times. We must therefore rest content with the partial information available and conjecture that in the blank portion of the map the contours would rise to between 2,000 feet and 3,000 feet above present sea-level. The best synoptic view of the Wealden structures is thus furnished by the map of anticlinal axes (Fig. 6); but even this, it should be noted, is not complete. The recognition of structural complexities in the regions of varied lithology in the Central Weald and on the Wealden margins is relatively simple, but in the intervening Weald Clay outcrop structural mapping has so far proved virtually impossible. The interesting structures of the High Weald are thus isolated almost as effectively from their natural prolongations in the western Weald and Wessex as they are from their presumed continuations across the Channel in Picardy and the Bas Boulonnais.

In Wessex the folds can be grouped in three main structural zones, but this division cannot be recognized in the Weald. Not only is the southern zone not represented at all, but by their progressive broadening and the appearance of subsidiary fold zones, the central and northern zones become barely separable. Both may be traced directly from Wessex into the western Greensand tract, and both certainly have their continuations in the Central Weald. The folds of the South Downs are thus seen to belong to a new and different group, while, on the other hand, the northern Weald lies beyond the main belt of folding altogether. The whole area northwards of the railway line from Dorking and Redhill to Ashford and Folkestone is destitute of any major structural complexities and has its tectonic affinities with the London Basin area.

We have already noted that even in Wessex the northern and central fold zones are markedly convergent, so that it is not possible to say whether it is truly the northern belt of folds which enters the Weald at its north-western angle to form the strong Peasemarsh anticline with the associated Hog's Back fractures. This zone of disturbance maintains its eastward course to Dorking, in part still faulted on its northern flank. It is then lost in the Weald Clay until we reach the Central Weald, though it is probable that its line is indicated by the inflexion of the outcrop and scarp of the Paludina limestone about five miles south of Redhill. In the High Weald we believe it to be represented by the Penshurst fold which runs by Chiddingstone, Pembury and Cranbrook and is again faulted on its northern margin. On its southern flank it is accompanied by an anticlinal flexure through Cowden, recalling the Elstead line which accompanies the Peasemarsh fold. The high probability of this correlation of the Penshurst and Peasemarsh axes has apparently escaped the notice of geologists, no doubt because of the respect naturally evoked by the elegance of Jukes-Browne's well-known synthesis.[10]

The folds of the central belt of Wessex – the Stockbridge line and the stronger folds of Warnford and East Meon – pass into the western Weald as the anticlines of Hindhead and of Petersfield-Fernhurst respectively. Two hundred square miles of the Weald Clay outcrop separate them from their presumed representatives in the aligned group of folds which run eastwards across the Central Weald by Ashdown Forest and Ticehurst to the Isle of Oxney on the borders of Romney Marsh. Between this group of folds and the Penshurst group lies a complex basin structure, much broken by faults, in whose lowest portions, south-west of Tunbridge Wells, outliers of Weald Clay are still preserved. This is sufficiently distinctive to warrant a name and may be termed the Groombridge depression.

It will be noted that if the Penshurst fold is correctly correlated with the northern fold zone of Wessex, this depression falls into the same zone which farther west holds the larger depression of Andover and Salisbury Plain. On the southern side of the Crowborough fold is another noteworthy depressed zone which crosses the High Weald from side to side and, until recent times, must have divided the outcrop of the Hastings Sands by a continuous strip of Weald Clay. Beyond this region a new and complex fold group occurs. It arises from the Weald Clay in the Ouse valley north of Lewes and runs by Brightling and Mountfield, where the only Jurassic outcrops in the Weald are revealed in valley inliers, and is continued by the more southerly Battle axis which reaches the sea at Fairlight.

In southern Sussex the folding again continues that displayed in Wessex. Two groups of folds, each comprising short anticlinal elements arranged *en echelon*, run almost east and west. Since the main outcrop of the Chalk trends in general from W.N.W.–E.S.E. it results that the folds cut obliquely across the South Downs, each group beginning close to the Eocene outcrop at its western end and passing eastwards into the Wealden terrain. The first arises with the anticlinal elements of Stoughton and the Dean valley noted earlier, passes across the Chalk escarpment at the re-entrant west of the Arun gap, and is continued by the Greenhurst and Pyecombe folds. Both are notable for the steepness of the dips which they display, 16° and 25° being recorded in the limbs of the former flexure. The second group runs eastward from the vicinity of Brighton to Pevensey Bay and comprises the echeloned elements of Hollingbury Castle, Kingston-near-Lewes and Pevensey. The accompanying synclinal flexures are particularly well marked by the occurrence of two minute Eocene outliers in the heart of the Downs at Falmer, and by the bold salient of the Chalk at Mount Caburn near Lewes. Still farther south, the most intense of the flexures of southern Sussex is seen where the Portsdown fold is continued eastward to be truncated by the coast at Worthing. The accompanying Sussex syncline, however, may be traced across the intervening bay to the neighbourhood of Newhaven and Seaford and we may suspect the presence of the accompanying upfold also at no great distance from the coast.

Within the Central Weald the lithological diversity of the rocks makes it possible to detect much structural detail which cannot be traced either in Wessex or the marginal tracts of the Weald. None of the anticlinal lines is simple, the main fold being frequently accompanied by parallel minor 'rolls'. Moreover, each of the main axes is accompanied by powerful longitudinal faulting, generally in the northern flank of the fold (Figs. 7 and 8). In all some five zones of strike-faulting can be made out. The first bounds the Hastings Sands outcrop along much of its northern edge, and the second is the Lamberhurst-Rolvenden-Appledore line, continuous for twenty-five miles and resumed farther west between Tunbridge Wells and East Grinstead. Southwards is the less continuous Eridge-Hawkhurst-Rother valley line associated with the Crowborough fold. On the farther side of the latter axis, a fourth zone is traceable continuously from the southern flank of St. Leonard's Forest by Mountfield, to Playden; in its eastern half it lies on the north flank of the Fairlight fold. A less considerable line of fractures completes the series on the south, running eastwards from near Cuckfield to the coast at Bexhill.

It inevitably appears at first sight as an anomaly that faulting is so much more clearly evidenced in the Central Weald than in other parts of the folded tract. Only in the highly disturbed zones of Purbeck and the Hog's Back, and in the extreme

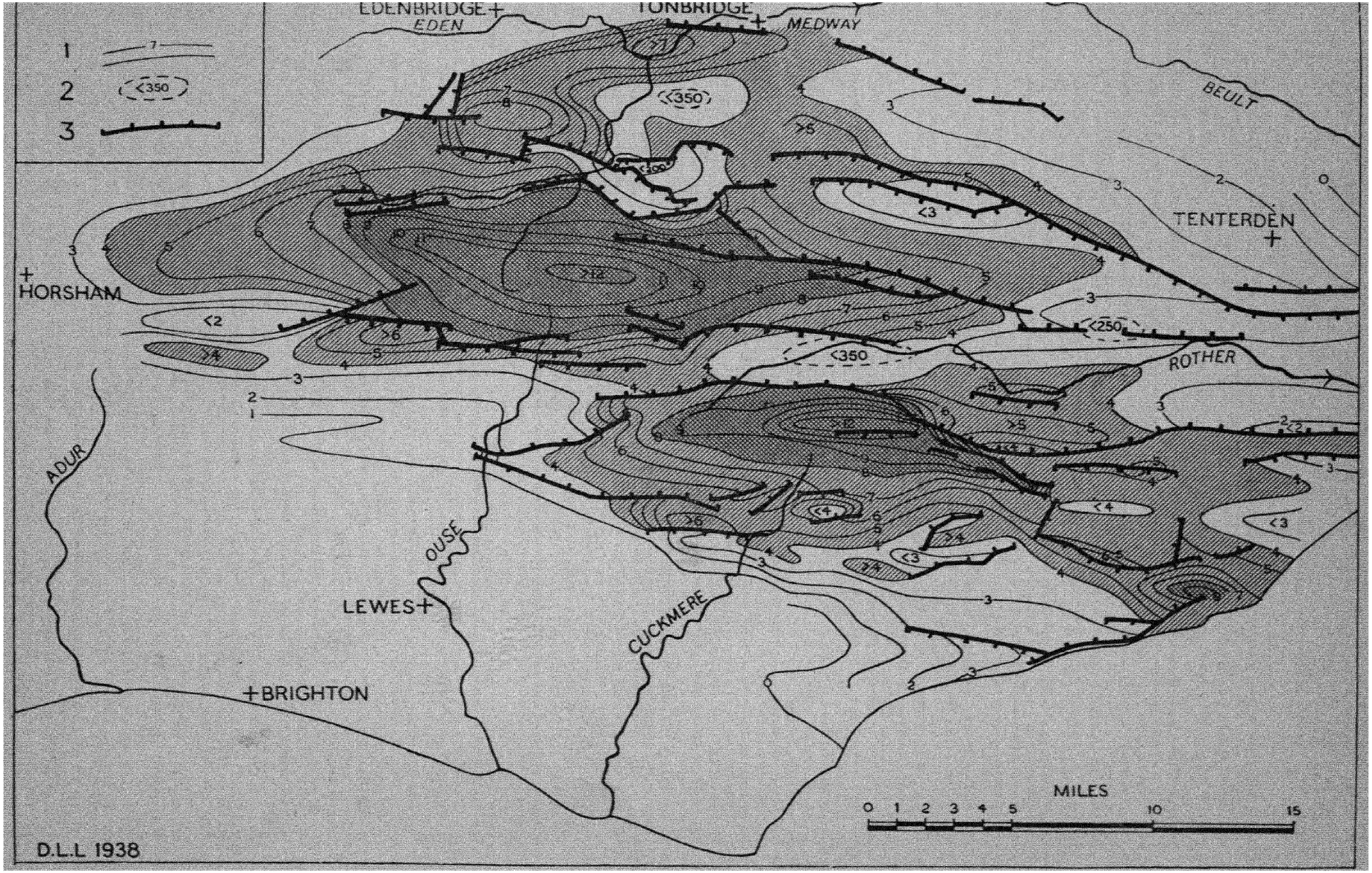


FIG. 8 – The Structure of the Central Weald. 1. Contours representing the form of the surface at the base of the Weald Clay at 100-foot intervals; heights in hundreds of feet. 2. Contours interpolated in centres of structural basins; heights in feet. 3. Principal lines of faulting.

west of the region in association with the Warminster and Wardour folds, are displacements of comparable length and magnitude to be found. Several reasons may be given in explanation. The effect is no doubt in part illusory for neither in the Weald Clay nor in the Wessex Chalk can fractures be readily identified, and it is noticeable that in the Lower Greensand belts where structural mapping is possible, strike-faults to some extent reappear. Nevertheless, it seems that more than a mapping failure is involved, and we may fairly surmise that the difference in response to folding stresses reflects greater mechanical strength in the rocks concerned, or that it results from the extra height of the great periclinal bulge of the Weald, as compared with the 'saddle region' of the Wessex Chalk. Structurally their difference of level must be the equivalent of quite 3,000 feet, while in comparison with the London Basin to the north and the Sussex syncline to the south the difference in tectonic elevation must be even greater. It is these differences, of course, which give rise to the regional dips and it is instructive to compare them with the amplitudes of the minor disturbances. The decline in the structural planes away from the Weald towards the north, south and west is effected over distances of the order of 30, 15 and 60 miles respectively. The regional dips are thus of the order of 1°, 2° and $\frac{1}{2}^\circ$ in these directions and in the central area are not apparent at all. The minor folds of both Wessex and the Central Weald on the other hand commonly show amplitudes of many hundreds of feet, and in a few cases more than a thousand feet, in a few miles only. Locally, therefore, they completely dominate the tectonic situation. Even the faults cannot compare with these magnitudes, for in the Central Weald and western Wessex they rarely possess downthrows of more than 200 feet. Only the Hog's Back and Purbeck faults considerably exceed this magnitude and these are associated with correspondingly larger disturbances. These simple figures serve to correct an impression which has become fairly widely current. It regards the Weald merely as a broad uplift practically uncomplicated by minor folding, but much cut up by important longitudinal faults. The interpretation here adopted is illustrated in the scale sections of Fig. 7.

(iv) THE MINOR STRUCTURES OF THE LONDON BASIN

We come finally to a consideration of the relatively insignificant structural 'rippling' which diversifies the broad simplicity of the London Basin. In part, these gentle flexures represent incompetent adjustment of the thin Neozoic cover to deformation of the thick and rigid undermass, but in part they are no doubt 'foreland' ripples lying beyond the main belt of folding. The forces that gave rise to the latter were spent on or south of the great declivity in the floor which forms the northern boundary of the Wealden depression.

From the contour map of the sub-Eocene surface (Fig. 5) we may judge the magnitude of the larger undulations; they have amplitudes varying from 50 to 200 feet and the gradients on their flanks are rarely steeper than about 50 feet per mile, save in the vicinity of the Thames valley anticline, and under parts of South London. It is important to notice that wells and borings are not sufficiently numerous, even around London, to reveal more than the broad outlines of the sub-surface contours. Much significant detail is perforce lost and Fig. 9 probably gives in some respects a truer picture of the structural character of the area. It is based not only on the sub-surface configuration of the Chalk, but upon the structure of the Eocene strata themselves, where decipherable. It must, however, be strongly emphasized that the lines on the map are lines of 'structural tendency', not con-

tinuous folds; i.e. they link aligned structures across tracts of country where actual structural evidence is absent or scanty. Close study of the matter soon convinces the observer that he is dealing with a faint but complex 'dimpling' or minor waving of the structural surfaces, which persists throughout the Basin, but whose constituent elements are often discontinuous and ill-defined. The lines of Fig. 9 are designed to bring out such elements of regular pattern as can be discerned in the complex whole. In spite of the small size of the folds they possess considerable importance in that they have been the only guiding elements in the erosion of this very simply constituted area, and are in evident relationship to the relief and drainage.

Though the structural pattern revealed in Figs. 5 and 9 is complex at first sight it may be analysed into several separate overlapping and interfering elements as follows:

1. There is a clearly marked anticlinal zone along the Thames valley comprising a series of elongated domes. It marks the continuation of the persistent tendency to uplift manifest in earlier periods, and may be regarded as the most northerly of the main Alpine anticlinal lines. Its distinct constituent elements include, from east to west, the Thanet dome, the Cliffe dome with its northern edge hidden beneath the Thames alluvium, and the Purfleet-Grays dome, which brings the Chalk conspicuously to the surface on Thames-side. Farther west there are dome structures near Charlton, and between Lewisham and Greenwich. Individually, these, like the Purfleet dome, trend N.E.–S.W.; so that the anticlinal zone as a whole is compounded of inclined elements, *en echelon*. Beyond Lewisham the prominence of the anticlinal structure is reduced by the crossing of two important fault-lines (see below) but a gentle anticlinal curvature of the Chalk surface can be traced as far west as Barnes. At Richmond a low dome-shaped structure of N.E.–S.W. trend recurs. From Grays to Richmond, the anticlinal zone trends slightly south of west, roughly parallel with the northern edge of the Weald, while east of Grays its line swings E.S.E. in conformity with the major deflexion at the line of the Medway gap. Eleven miles west of Richmond is the well-marked Windsor dome, which lies somewhat north of the general anticlinal line. It may nevertheless represent a westerly recurrence or continuation of the anticlinal tendency, though a fold of another trend is also involved in the structure. It is noticeable that the distinctness of the anticlinal structures of the Thames valley zone diminishes westwards, as the line leaves the area of the London Platform, and the floor sinks to greater depths. This fact tends to confirm the interpretation of the Thames valley anticline as an essentially posthumous expression of an anticlinal structure in the floor.

In South-East London there is an area of E.–W. folding between Shooters Hill in the north and a line through Eden Park and Swanley in the south. These folds have a visible effect on the surface outcrops and are in fact more strongly marked than most of the minor structures of the Basin. They terminate somewhat abruptly westwards near the Kent-Surrey boundary, but range eastwards for considerable distances. They may be regarded as subsidiary ripples, genetically related to the main Thames valley axis, and as the Tertiary culmination of the intra- and post-Cretaceous folding in this tract.

2. In the central area of the London Basin, both north and south of the Thames, there is folding along N.E.–S.W. lines. The most conspicuous anticlinal element in the series is responsible for the inlying tracts of Chalk and Reading Beds at

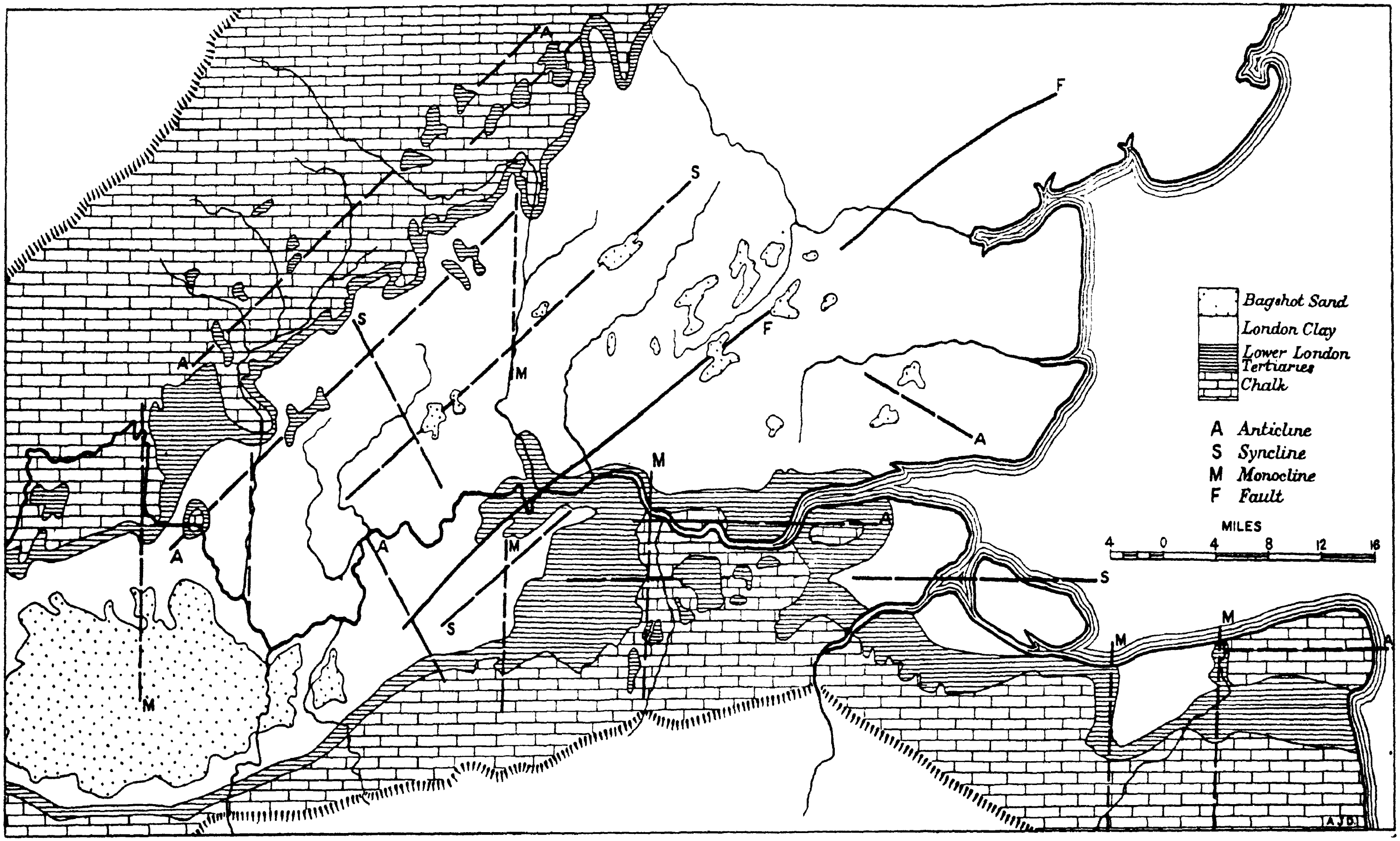


FIG. 9 – The Minor Structures of the London Basin.

Northaw and Pinner respectively, and the same line continued south-westwards passes through the Windsor inlier. Northwards, a parallel anticlinal roll passes close to Radlett and South Mimms, where its effects are evident in the form of the Eocene edge. The contours of the Chalk surface reveal a roughly parallel anticlinal flexure between Islington and Romford. Faint synclinal lines of the same series are marked by the chains of Eocene outliers on the Chiltern dip-slope, ranging parallel with the general strike. The Bagshot outliers within the main London Clay outcrop are also ranged along N.E.–S.W. lines, and may be taken as marking nearly, but not exactly, the position of synclinal axes. The Chalk surface contours supplement the evidence here, revealing a syncline through Willesden and Hampstead, continued between Loughton and Brentwood in Essex, and a parallel fold along the Ingrebourne valley in South Essex, continued in South London, where relatively sharp synclinal flexuring is revealed near the Crystal Palace and between Mitcham and Surbiton. Another syncline in the series crosses the Thames east of Grays and is largely accountable for the preservation of the Swanscombe Eocene outlier.

In the central parts of the Basin these N.E.–S.W. folds are truly longitudinal, i.e. closely parallel with the general strike. Traced farther afield they change direction but retain this general relationship. Thus they swing round through E.–W. to N.W.–S.E. in the Bagshot country, in conformity with the outcrop of the Tertiary edge, while in East Essex there is evidence, as near Rayleigh, that their trend is again N.W.–S.E. parallel with the regional strike.

3. A belt of faulting of N.E.–S.W. trend crosses the line of the Thames near Greenwich. In South London a major fracture passes from Surbiton, north of Tooting and Dulwich to New Cross. It has a northerly downthrow exceeding 100 feet in the west. A parallel fault with a smaller throw in the same direction is traceable from Forest Hill to Greenwich. The first named fault is probably continued in Essex as far as Beckton, while south of it another important fracture sets in along the line Dagenham, Hornchurch, Brentwood. It has a southerly downthrow ranging up to more than 100 feet. It is probable that this line is continued farther to the north-east by that of the mid-Essex fault, marked approximately by the Tiptree Heath ridge between Chelmsford and Colchester. It has been deemed probable that the East Anglian earthquake of 1883 was due to a movement along this line, which has shown evidence of recurrent instability from early Eocene times onwards.

4. In the London district, distinct 'Charnian' elements enter into the folding plan, as between Barnes and Harrow, near Selhurst, Chislehurst and elsewhere. Folds of so definite a N.W.–S.E. trend are inconspicuous or absent in the other parts of the Basin and it is probable that those occurring in the London district are to be regarded as accommodation structures in association with the main Charnian cross-warp. They serve to emphasize in the existing structure of the Basin an ancestral trait of which we have found abundant evidence during the earlier formative periods.

(v) THE TOPOGRAPHIC EXPRESSION OF THE ALPINE STRUCTURES

The importance of the structures described in the preceding pages arises from the profound influence which they have had upon the whole subsequent course of landscape evolution. Not only did they bring into existence, in essentially their present form, the major regional subdivisions of south-eastern England – the Weald, Wessex, the London and Hampshire Basins and East Anglia – but they are

responsible also for a great deal of the distinctiveness possessed by most of the minor physical regions within the larger units. Such examples as the Isle of Thanet, the Forest of Bere and the Vale of Wardour may be cited as cases in point. Moreover, it is from this epoch that the older elements in our drainage system must be dated, and although over a large part of the region a newer drainage has arisen independent of this structural pattern, its independence has often proved short-lived and the present drainage is everywhere endeavouring to adjust itself to the structure. The question of the relation between the patterns of folding and drainage is of such importance that it is dealt with more fully below. We may note here, however, the general topographic expression of the folding in the present landscape. That expression is not permanent, but subject to continuous evolution, and the same fold may be represented now by inverted, and at a later time by normal relief. Its present condition is the outcome of the somewhat accidental disposition of structure and lithology with reference to present base-level. It accordingly shows wide variations in the different parts of our area.

It is to be expected that the surface forms assumed by minor folds of the Weald will differ from those of Wessex, and that those of the London Basin will differ from both. Partly this results from differences in the nature of the flexures in these regions, and partly from the differing character of the strata which they traverse. It is noteworthy, for example, that in the Weald, which is now regarded as the very type of what Buckland termed in 1825 'valleys of elevation', the minor folds usually show normal or positive relief, upland corresponding with upfold. On the other hand, Wessex, from which Buckland cited so many striking examples of inversion of relief on the minor anticlinal axes, is, taken as a whole, a region of concordant relations between surface and structure. No single fact explains these differences, which arise from the varied relations of strong and weak rocks to past and present base-levels and must be considered in detail.

The Weald

The centre of the Wealden pericline is marked by the uplands of the High Weald, comprising two sandy formations separated by the Wadhurst Clay. The lithological contrast between the Tunbridge Wells Sand and the underlying clay is, however, insufficient to give a continuous scarp rim overlooking a 'Weald within a Weald'. Instead, the topography is dominated by the uplands formed by the lower (Ashdown) sand, which is elevated along the lengths of the Crowborough and Battle axes. This formation itself is so thick and descends so close to base-level that the development of inverted relief is restricted to the cases in which valley inliers of Purbeck Beds are exposed in the Battle fold. The third major anticline of the central area – that of Penshurst – is almost without effect upon surface relief. Planation at about 400 feet has levelled it off and locally the Eden and Medway courses have been superimposed upon it. Between these anticlinal lines the synclinal zones form topographic depressions and in many cases the actual stream pattern is markedly guided by the long belts of strike faulting.

The best example of inverted topography in the Weald is perhaps the scarp-rimmed window through which the Weald Clay appears in the midst of the Greensand outcrop at Peasemarsh, near Guildford. At its western end the Hythe Beds form an abrupt scarp curving round behind the village of Compton, and in its eastern half the northern scarp is surmounted by the Folkestone Sands to build the well-known and picturesque ridge of St. Martha's and the Chantries. At

Hindhead, on the other hand, the base of the Lower Greensand is not sufficiently far above base-level for inversion, and the Weald Clay is only just exposed in one or two of the deeper 'bottoms' which score the flanks of this broad swell of cherty sandstone. This material can give rise to the most impressive of all the Wealden escarpments as is well seen in the Vale of Fernhurst farther south. This comprises two elements, the western being enclosed save where it opens eastward into its neighbour near Linch, and where two water gaps breach its southern wall. The eastern and larger portion is open to the Wealden plain on the east and is drained axially in this direction. The stream, however, does not pass eastward to the Arun, but turns southward through a water gap in the scarp rim at Lodsworth, thus showing that it was formerly enclosed on all sides.

The Greenhurst fold is inverted, but despite its abrupt flexuring, the scarps that overlook it are diminutive, owing to changes in the lithology of the Greensand and to previous base-levelling; the fold is barely traceable on a topographic map. A good section across it is figured in the Brighton memoir.[11] The neighbouring Pyecombe fold is even less conspicuous, save for the indentation which it makes in the Chalk scarp at Poynings, and its northern wall of Greensand has been practically destroyed.

The folds which traverse the South Downs do much to complicate the relief of the dip-slope, but they are rendered less conspicuous by being repeatedly cut across by the many dry valleys which, as will appear later, have been superimposed upon them. Even so the Dean valley anticline has been unroofed along its whole length and the anticline of Hollingbury Castle, near Brighton, partially so. Steep-walled combes cut into its flanks, but between them the crest of the arch survives intact and provides a relatively easy route for the road from Rottingdean to Falmer. Both folds cause abrupt deflections of the Chalk escarpment. The boldly projecting salient on the line of the complementary Falmer syncline, severed by the course of the Ouse at Lewes, is well known, while the enlargement of the Ouse valley, known as the Brooks, is in essence a 'valley of elevation' open toward the east, and revealing the underlying Upper Greensand in its floor.

Wessex

Northern Wessex may be described summarily as an upland of moderate relief and broadly synclinal structure, developed wholly on Chalk and terminating at the eastern and western ends of the Andover-Salisbury Plain depression in bold escarpments of Chalk and Malmstone overlooking the lowlands of Somerset and the western Weald. It is bounded on its north and south margins by upland ridges following strongly anticlinal belts which have been breached by erosion at their culminations to give some of the finest examples of small-scale inverted relief that this country has to show. Throughout the central portion of the area, however, uninverted relief is the rule. The synclinal tracts are marked by minor longitudinal valleys, of which those of the Micheldever stream and upper Itchen may serve as examples, and the anticlinal axes by the low swelling ridges which are the characteristic feature of the 'Hampshire Downland'.

The chief interest naturally attaches to the scarp-rimmed vales produced by the unroofing of the anticlinal culminations. Buckland,[12] who first described them, believed that his designation of them as 'valleys of elevation' was literally applicable, and saw clearly in the Vale of Kingsclere 'the bursting up of the Upper Greensand or firestone from beneath and between two opposite escarpments of chalk'. He

observed how their drainage 'is generally effected by an aperture in one of their lateral escarpments and not at either extremity of their larger axis', and he thought it improbable that 'the power of running water alone would have forced open such valleys as these in question, without causing them to maintain a more equable breadth, instead of narrowing to a point until they end in the body of the chalk'. When the Wessex Chalk was resurveyed on the six-inch scale fifty or so years ago these 'valleys of elevation' again attracted attention and Osborne White noted particularly their multiplicity of drainage outlets. He concluded that such valleys as the Vale of Ham had been formed 'by the expansion of the upper, cirque-like portions of several adjacent combes trenching the rocks on the northern limb of the fold'.[13] He inferred that in the beginning these combes had been small and numerous, but that, as they expanded and intersected, the less favourably situated ones were absorbed by their fellows, and ultimately their number was reduced to the present two or three. As an example of the early phases of this evolution he pointed to the expanded combe heads immediately east of Kingsclere Vale,[14] while that vale itself and the Vale of Ham provided excellent models of the later phases of drainage integration. Since then these valleys have received little attention, but it does not seem that their features have yet been wholly explained.

Between the Vales of Kingsclere and Ham is the long inlier of the Lower Chalk near Woodhay, three or more miles in length, but far more conspicuous on the map than on the ground. As seen from the scarp which overlooks it from the south it conveys not the least suggestion of a scarp-walled inlier, but appears as a bench, at the foot of the main escarpment, nearly a mile wide and partially dissected by a number of small obsequent valleys. The latter show some expansion in the Lower Chalk outcrop, but it is observable that this outcrop commonly continues across the intervening spurs without making any recognizable feature in their profile. It is clear that these little combes have nothing to do with the formation of the inlier, for they are later than the bench feature which is cut across the outcrops of all the strata from the Lower Chalk to the Bagshot Sands.[15] It will be later shown that the altitude (600 feet) and general relations of this bench indicate it to be part of a wave-cut platform of Pliocene times, and that the scarp behind it represents the actual coastline of that period.

It is evident that the neighbouring Vales of Ham and Kingsclere have also been carved from the same platform. The smooth, unindented character of the northern Chalk outcrop in both vales derives not so much from the high dip (which rarely exceeds 25°) as from this former planation, and this accounts also for its relative uniformity of summit level which never surpasses 610 feet. Similar conditions obtain also along the northern margin of the Vale of Pewsey until Martinsell Hill rises abruptly to 948 feet, and, indeed, this portion of Pewsey Vale with its northwardly-directed drainage outlet at Crofton resembles the Vale of Ham very strongly. The remainder of the vale, however, has a different aspect and history. Draining wholly towards the south by the Wiltshire Avon and Bourne, and bordered both to north and south by high ground rising to 700 feet or over, it has been produced wholly by sub-aerial erosion, albeit perhaps in two cycles. Possibly the northward draining portion was originally distinct (the Vale of Grafton) in the same way that the Ham-Woodhay inlier is to-day separated from the big wall-sided leaf-shaped combe of Combe village, or as the Vale of Kingsclere must have been separated from the expanded combe head above Litchfield until the intervening escarpment was breached on either side of Beacon Hill. In any case it is

the Grafton Vale which is the true expression of the main Pewsey anticline which follows its length from Tidcombe to Wootton Rivers, thence to pass under the northern escarpment with its bold hills situated on the very curve of the arch, and so to leave the major portion of Pewsey Vale wholly on its southern flank.

Of the other denuded periclines of Wessex little need be said. On the Winchester-Petersfield fold zone, the group of inliers in the Upper Meon valley are interesting, since they illustrate admirably the process which White believed to have taken place on the northern folds. Three northward-flowing tributaries of the Upper Meon have opened up wall-sided combes in such close proximity that their dividing walls have become breached and a measure of integration is in progress. The upper and lower Vales (of East Meon and Whitewool respectively) are the active agents and the intervening Drayton stream has been almost extinguished between them. All three, however, are on the point of being fused into a still larger whole. The Vale of East Meon has already lost its eastern wall and is open to the Weald in this direction; the Vale of Whitewool is separated from the Vale of Warnford – the enlarged portion of the Lower Meon valley – only by a single, lofty, knife-edge ridge.

The well-known valley of Chilcombe, formed by the inversion of the Winchester fold at that place, also shows admirably the process of fusion of originally distinct combes. A col at 250 feet in the northern rim carrying the Winchester by-pass, marks an outlet that is now wholly extinguished, while, on the opposite side, the notch which isolates St. Catherine's Hill only 'drains' a minute bench area that projects bastion-like in front of the gap into the main vale. Farther along, the combe, having its outlet at New Inn, is almost merged in the main vale, but that opened up in Fawley Down has only been breached at the north-western corner. Finally, the Temple valley draining northwards is virtually intact, but liable to early encroachment on its western side.

In Wiltshire, only the Vale of Bower Chalke and its neighbours are comparable with the cases just described, for the Vales of Wardour and Wylye are older and their evolution is more advanced. Near Bower Chalke half a dozen lateral tributaries of the Ebble – a resequent or entrenched longitudinal consequent stream – have opened up scarp-walled combes near the head of the valley, and these, by fusion, have practically destroyed its southern wall. As a result the valley has developed an expanded head, whose southern limit is the bold scarp which looks down from Cranborne Chase and opens westwards into the Vale of Wardour. The latter is the most evolved of all the areas of inverted relief in Wessex, for its unroofing must have been an affair of an earlier cycle of erosion, and the present cycle has laid bare its complex internal structure. Below the main boundary scarp of the Chalk is that of the Upper Greensand, which is more broken, but hardly less bold. Both are much more strikingly and continuously developed on the south side where the dip is small, and except in the minor synclinal ripple of Hindon, are almost suppressed on the steeply-dipping northern limb. Wylye Vale must similarly have been breached in a previous cycle and has long been completely integrated, although the uplift has not been sufficient to permit the Upper Greensand to be breached except in a minute valley inlier which reveals the Gault just south of Warminster. Between the two Vales of Wylye and Wardour stands the Great Ridge, a structurally unexplored syncline which may carry a considerable outcrop of Belemnite Chalk at its eastern end. No other synclinal ridge of comparable size exists in southern England.

The folds of the Hampshire Basin are at best feeble and their topographic expression has been further weakened by the repeated base-levelling which the Tertiary tract has undergone. The ridge of Portsdown itself has not wholly escaped this fate and by no means adequately represents the whole area over which the Chalk is brought to the surface. Its culmination to the east is wholly planed down and buried. Its prolongation into the Tertiary area to the west is marked by a much broken but fairly well-defined ridge.

The folds of the south coastal belt, on the other hand, are so strong that they could not fail to be unroofed of their covering of Chalk before the present cycle of erosion opened. In the Isle of Wight, the Brixton and Sandown anticlinal elements have both been opened down to the level of the Weald Clay, and before they were so extensively breached by the sea, must have been among the most spectacular inversions in Britain. The axial drainage of the Brixton Vale may be reconstructed from the existing remnants, and the presence of river gravels along the present-day cliff tops. Between the two uplifts the Chalk is preserved in the intervening syncline, and earlier in the present cycle must have been continuous with the existing outcrops in the southern part of the island. In Purbeck, the Chalk is reduced to a hog-back ridge along the steep northern limb of a fold whose axial tract is occupied by the Purbeck and Portlandian limestones. These build a dome-like upland declining eastward with the pitch, and breaking away to the south in a fine scarp to overlook a tiny 'interior' lowland, formerly opened out by stream action, but now invaded and largely destroyed by the sea. Yet a little farther west, the topographic expression of the folding suddenly becomes positive where the Chaldon anticline builds a Chalk upland and the Lulworth syncline a valley. Beyond, inversion is again the rule, and the Vale of Sutton Poyntz, formed by the exposure of the Kimmeridge Clay beneath a bounding scarp-rim of Portland Stone, is the most striking inversion which Dorset can offer and was one of the cases which attracted Buckland's attention over a century ago.

The London Basin

Relief and folds in the London Basin are both on a smaller scale than in the regions just discussed, and as if to diminish the topographic contrasts still further, the major uplifts within the Basin have all been partially or completely planed off by the River Thames. Part of each of the inliers of Windsor, Deptford, Charlton, Purfleet and Cliffe have suffered in this way, and only the Thanet dome reveals the low rounded swelling Chalk surface that we might expect to result from the simple stripping of the Eocene beds. It is true that enough of the Chalk has escaped planation to provide the riverside bluffs of Purfleet and Windsor Castle, and the 'cliff' of Cliffe, but though these have been among the vantage points selected for early riparian settlement, they are topographically less striking than features built by other formations in the area. We may recall, however, the significance of these truncated domes in relation to water supply. Through them Thames water gains access to the Chalk. In Bermondsey it has for long given rise to pollution in the uppermost layers of the Chalk, necessitating the abandonment or deepening of the older wells.

The other instances in which uplift brings the Chalk to the surface within the main Tertiary outcrop (at Lewisham, Chislehurst, Northaw and South Mimms) are mere valley inliers, though in all but the first case they are marked by swallow holes and stream disappearance. In other cases, where the folding is still more

feeble, its effects can only be made out in the pattern of the drainage. Many of the minor streams show a preference for the N.E.–S.W. anticlinal lines characteristic of the area north of the Thames, notwithstanding the fact that the course may lie wholly within the apparently uniform London Clay. Portions of the valleys of the Pinn, Yeading Brook, Brent, Cobbins Brook, Roding, Wid and Blackwater all show this tendency. Between these broadly anticlinal valleys lie synclinal zones which offer more marked topographic expression. In these gently down-warped belts outliers of the Claygate and Bagshot beds are preserved as pervious cappings to the hills and ridges which rise abruptly from the clay plain of Middlesex and South Essex and do much to diversify it. Of similar character are the synclinal ridges of London Clay in South and South-East London, and those formed by the Lower London Tertiaries rising from the main Chalk outcrop of North Kent. More fragmentary, but essentially comparable, are the synclinal chains of Tertiary outliers which parallel the main Tertiary outcrop on the Chiltern dip-slope. Indeed, while the relief of the London Basin cannot in any real sense be described as 'inverted', a measure of correspondence of valleys with anticlines, and ridges with synclines must be regarded as one of its salient features.

CHAPTER IV

THE MID-TERTIARY CYCLE OF EROSION AND THE SUMMIT PENEPLAIN

In the physiographic evolution of most regions there comes a point in time when a history of predominant deposition is replaced by one of predominant erosion. The record provided by the stratigraphical succession is abruptly terminated, to be resumed only in an intermittent and fragmentary fashion, and the evidences available for physiographic reconstruction are thenceforward of a radically different character. In south-eastern England such a critical epoch was reached in Oligocene times when the long record of deposition was brought to an end by the onset of the Mid-Tertiary earth-movements. From that time down to the present day the phases of deposition have been so restricted in both space and time and their products so largely destroyed by later erosion that at best they can provide only a disjointed picture of a few episodes in the long period of later Tertiary and Quaternary time. Because of this inescapable deficiency in the stratigraphical evidence the main burden of elucidating these 'Dark Ages' must be borne by the evidences provided by the successive denudation stages. Instead of the clues available to the geologist in the lithological character and geographical distribution of sedimentary deposits, we have now to employ those afforded by the form, altitudinal relationships and geographical extent of *surfaces* which have resulted from former local or widespread base-levelling.

The essential basis of the technique for the morphological reconstruction of physiographic evolution thus comprises the recognition of former base-levelled surfaces now uplifted and partially dissected, or else buried and possibly in part exhumed. They represent periods of still-stand separated by relatively short periods of rising or falling base-level, and when their proper relationships are determined they offer a veritable chronology of denudation, which is independent of the doubtful witness of the superficial deposits, and is potentially more reliable and certainly more complete.

Little progress could, of course, be made toward the elucidation of such a chronology for south-eastern England until recent years, since the theoretical concepts upon which it is based have all been worked out within the last forty or fifty years. Nevertheless, the recognition of what we must now regard as the most important of all the base-levelled surfaces of the region, is nearly a century old. As long ago as 1846, Ramsay[16] recognized that the greater number of the hill tops and ridge crests of South and Central Wales, whatever their geological character, rise to much the same level and could, indeed, be regarded as having been derived, by the excavation of the present valleys, from a single continuous surface or plain of denudation, which in consonance with the views of his time, he attributed to the work of the sea. In the generation following Ramsay's classic observations, other workers had recourse to the idea of a plain of marine denudation represented by the present hill tops. Thus J. B. Jukes,[17] writing in 1862 of the rivers of southern

Ireland, found it possible to explain their present courses only by assuming that the original streams had been formed upon 'a surface considerably above any part of the present surface', which had been previously planed down by the sea. Fourteen years later Topley adopted a similar point of view with regard to the Weald. In considering the views of Col. George Greenwood, he expresses doubt whether the result of the long-continued action of rain and rivers upon an upheaved dome of Chalk 'would be the present system of longitudinal and transverse valleys. To achieve this result it is necessary that the country should be *planed across* so that successive rocks should in turn crop up to the surface'.[18] His belief in such planation by the sea was, however, based also upon the evidence of accordant summit levels, both in the English Plain generally and in the Weald in particular. On this point he is again worthy of citation, and in regard to South-East England as a whole he writes: 'If we draw a line from the south-eastern end of the Eastern Moorlands of Yorkshire, past the southern end of the Pennine Chain, the Malvern Hills, and the Quantocks, to the south-eastern corner of Dartmoor, we shall find that all the summits to the south-east of that line, with very few exceptions, are below 1,000 feet. The only exceptions are both on the Cotteswolds (the Inferior Oolite escarpment) north-east of Cheltenham; they are Cleeve Cloud 1,080 feet and Broadway Hill 1,032 feet*. The summits of the various hills and escarpments rise to 700, 800 and in a very few cases to 900 feet. They evidently point to the former existence of a great plain of marine denudation over this area. This plain is far older than the glacial period; for the escarpments around which the Boulder Clay and other deposits of that period have accumulated, have been carved out of it. It is later than the Eocene period; for outliers of that formation lie scattered over the plateaux, far up towards, and often upon the escarpments'.[18]

The Wealden region received more detailed discussion, and here Topley quoted in support of his thesis the altitudes of a fairly large number of summits, some of which have since been somewhat revised as the result of precise levelling. He recognized the importance of the close accordance of summit levels in a longitudinal sense, along each of the major uplands, the North and South Downs, and the Central Weald, and from his figures was led to conclude that the summit plane possessed a regional tilt toward the east. He also stressed the more significant though less perfect accord of summits in a transverse sense, along lines which passed across each of the geological formations in turn. Uniformity in this sense clearly argued that the planation occurred at some date after the rocks had been folded, and the age of the plain is thus broadly fixed as being later than the Mid-Tertiary earth-movements.

When W. M. Davis came to England in 1895, he brought with him clearer notions than those possessed by most of his contemporaries as to the power of fluvial erosion. He therefore felt himself under no compulsion to regard every planed-off surface as being the work of marine erosion; a plain of fluvial erosion was equally possible. On deductive grounds he argued that a scarpland region which had suffered such planation would show a number of distinctive features, viz. straightness of the escarpments in plan, a drainage system with a large proportion of subsequent streams well adjusted to structure, and bevelled summits to the uplands developed upon the more resistant formations. All these features, he observed, were to be found in the English Plain and to some extent found in combination.

* Precise levelling by the Ordnance Survey later corrected these figures to 1,070 and 1,042 feet.

He regarded their combined witness as sufficient evidence that 'the rivers of to-day . . . appear to be the revived and matured successors of a well adjusted system of consequent and subsequent drainage inherited from an earlier and far advanced cycle of denudation'.[19]

Davis's views were so divergent from those prevalent in England at the time, that no attempt was made either to prove or to disprove them in their application to South-East England until H. Bury,[20] in 1910, made a critical analysis of the denudation of the western Weald. As a result of his examination he materially increased the weight of the evidence in favour of a planation of the region, but he regarded it as being due to marine agencies. He pointed out that, in the Weald, straightness of the escarpments appeared to be due chiefly, if not wholly, to to parallelism with longitudinal folds, and that, in some cases at least, Davis's argument concerning the subsequent streams could be shown to be invalid. Evidence on this point was chiefly drawn from the widespread occurrence of fragments of Lower Greensand chert upon the crest of the North Downs. Clearly such debris must have been carried to this position across the site of the present subsequent Vale of Holmesdale, and whether the emplacement of the chert-bearing gravels be referred to fluvial or marine action, it is clear that this particular subsequent valley must have arisen wholly in the present cycle. By similar arguments Bury was able to show that both the subsequent tributaries of the Wey are also of quite late development, having arisen well within the span of the present erosion cycle. This late out-growth of subsequents argued strongly against Davis's contention that the drainage system is in its second cycle. If the streams are survivors from a previous cycle, why did they not earlier develop subsequent tributaries? If, on the other hand, they are still in their first cycle how else could they have arisen but upon an emerged plain of marine denudation?

At this date, then, the evidence brought forward in favour of the idea of planation was drawn either from the accordance of summit levels and the bevelled form of the escarpments, or from features in the development of the drainage systems. On the whole, moreover, the evidence favoured a marine origin for the plain. But practically no attempt was made to relate this inferred marine plain, as regards its age and geographical extent, with the known Pliocene outliers of South-East England. Later it was shown that these high-level marine Pliocene deposits do rest upon a true plain of marine denudation which could be traced over most of the London Basin and in parts of the North Downs and Chiltern Hills.[21] The same work showed, however, that the highest portions of both uplands – roughly the areas above 700 feet – escaped submergence (p. 55). These observations have thus permitted a solution of the long-standing difficulty as to the marine or sub-aerial origin of the summit plain of South-East England and have reconciled the conflict of evidence upon which the older views were based. Over much of the area, including the region of South-West Surrey from which Bury drew his best evidence, true marine planation was proved. Other tracts were shown equally certainly not to have been submerged and here the planation, already inferred upon other grounds, must necessarily be attributed to sub-aerial agencies. Marine erosion, indeed, merely completed the work of rain and rivers by perfecting, over limited areas, a planation that was already far-advanced. Further work has brought to light other criteria which assist in the delimitation of the portions of the peneplain which were submerged, from those in which sub-aerial erosion was never interrupted. These points, however, may well be deferred until a later section where

a full discussion of the Pliocene phase is attempted. Here it is important simply to emphasize the significance of the transgression as revealing definitively the extent of the unsubmerged areas, and as an invaluable index of the age of the planation. To whatever epoch in the Pliocene period the deposits of the marine phase are assigned by the palaeontologist, the preceding phase of widespread base-levelling must have been far advanced by early Pliocene times.

We are thus provided with a major landmark in our denudation chronology, the summit peneplain of south-eastern England being its visible expression. It marks a critical point in time, the end of one cycle and the beginning of another. Its production was the work of that long period of still-stand which we term the Mid-Tertiary erosion cycle. Its uplift to its present position and dissection in its present form have been accomplished during the cycle which is yet incomplete, the cycle of late Tertiary and Quaternary time. It is the oldest feature in the landscape of to-day, a surviving relic from a previous order of things, and its destruction and disappearance is now all but accomplished.

Here we may turn from the consideration of the evidence which has led to the understanding of the nature and age of the summit peneplain in South-East England to notice briefly the observations made by earlier writers upon its western extensions in Wessex and the south-west. Several portions of the upland surface of these regions have been recognized as plains of denudation, but their age has been largely a matter of rather vague inference and few objective criteria have been advanced to settle the question of their origin, which, following British tradition, has usually been attributed to marine agencies.

In the same year that Davis published his classic paper, 'On the Development of Certain English Rivers', Jukes-Browne[22] described the origin of the valley system of the Dorset Downs. He there recognized the existence of extensive flat interfluvial upland surfaces which bevelled indifferently the several stages of the Chalk including the hard bands of the Melbourne and Chalk Rocks. Associated with these upland flats he found deposits of 'reddish sandy loam or clay, full of flints', and he interpreted both the clay and the surface on which it rests as resulting from marine action. This surface of marine erosion he saw must be older than the present valleys, whose initiation he regarded as 'Pliocene or even Miocene'. Rather similar conclusions had been advocated some four years before by Rev. W. R. Andrews[23] in respect of the uplands on either side of the Vale of Wardour. He regarded their almost level ridge rops as relics of a former plain of erosion, tilted gently toward the east, which he tentatively attributed to the action of a Pliocene sea. As part of the evidence for this plain Andrews cited the drifts which cap the Great Ridge continuously for many miles, and the 'relics of old gravel with pieces of Upper Greensand chert' which occur on the crest of the southern escarpment, just as Jukes-Browne had attached much importance to the similar drifts in Dorset. In both cases, however, the drifts go far to negative the inference of marine planation which they were intended to support, for they are undoubtedly sub-aerial deposits and have, indeed, the characters of a land-wash rather than those of a fluviatile gravel. If they are, indeed, contemporary with the surface on which they lie, and the presence of chert fragments on the scarp crest does suggest they they are older than the present features of relief, then we should probably regard them as relics of the regolith or mantle of deeply-weathered rock-waste which would naturally be associated with the Mio-Pliocene peneplain.

Clement Reid was another worker who clearly believed that planation had been general in this region, but his writings on the subject are brief and probably do less than justice to his views. In describing the Ringwood district[24] in 1902, he suggested that the Mid-Tertiary folding episode was followed by 'a long period during which the (anticlinal) ridges were planed down by the sea'. He then speaks of 'the gently undulating plain thus formed', being trenched and cut into by rivers as the result of elevation in the Newer Pliocene period.

Ten years later H. J. O. White questioned whether this planation might not be sub-aerial rather than marine, and in a considerable series of survey memoirs from his pen this conception was much developed and extended. In particular we must notice the diagram with which he illustrated his account of the Shaftesbury district.[25] In this figure it is made clear that here at least the summit peneplain, represented by the bevelled upland surfaces of the Chalk downland, is to be clearly distinguished by the field evidence from the exhumed portions of the sub-Eocene surface which occur on the lower parts of the dip-slope. Both surfaces are inclined toward the south-east, but the earlier one much more strongly so that the two surfaces intersect and give rise to quite contrasted landscapes (see below, p. 56).

While the reality of the planation of South-East England is not now in question it is nevertheless true that no account of the character and geographical distribution of the summit plain has hitherto been attempted. Surviving remnants of the summit peneplain are nowhere common or extensive in the region. They are, in fact, preserved at all only by the favourable chance that the degradation of the permeable limestone uplands fails to keep pace with the reduction in the elevation of the region as a whole. These areas of calcareous sub-stratum have remained generally in the stage of late youth, while neighbouring outcrops of clay and sand have advanced to maturity, probably in more than one partial cycle. In particular, it is on the Chalk uplands of Wessex that the most considerable of these remnants of the summit plain survive, and a summary of the field relations in certain of these areas may be given here.

Standing anywhere in the south central part of Salisbury Plain one may look southward across the Wylye valley to the long even crest-line of the Great Ridge (Fig. 10). From such a viewpoint the ridge appears to have the character of a plateau, its summit surface being separated by a sharp topographic break from the valley slopes and spurs of lower levels. It suggests strongly by its appearance that its upper surface belongs to quite another morphological cycle than that represented by the smooth, well-modelled spurs and slopes that descend towards the modern valley. This upland comprises one of the largest and most instructive surviving remnants of the Mio-Pliocene peneplain. At its eastern end it pitches rather more definitely than elsewhere. If we except these easternmost two miles, the ridge rises gently from 600 feet near Grovely Lodge in a W.N.W. direction for some 11 miles to 784 feet near Brixton Deverill. Or passing due westwards it takes some 15 miles to rise to the same altitude at Whitesheet Hill north of Mere.* Concurrently the ridge broadens and becomes dissected by a branching dry-valley system, but ignoring the minor valleys incised below the plateau surface, the latter in its western part attains a breadth of about 5 miles at 700 feet. It thus ranks as a topographic feature of some magnitude with maximum dimensions of 15 by 5 miles and area of 35 to 40 square miles.

* The highest points of the area are actually Long Knoll (945 feet) and Brimsdown Hill (933 feet), both a little further west. Consideration of these eminences is for the moment deferred.

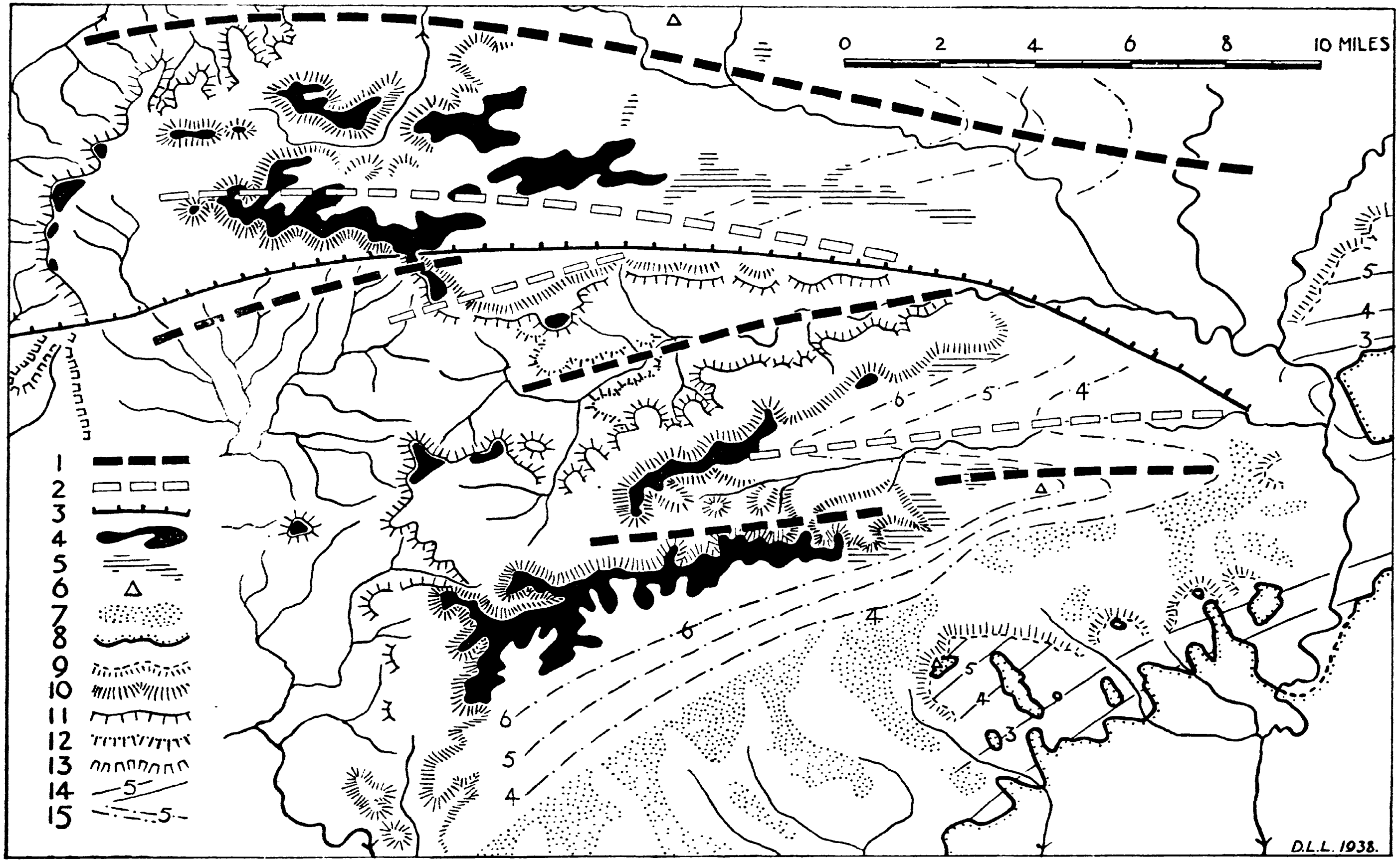


FIG. 10 – The Upland Plains of South Wilts. 1. Anticlines. 2. Synclines. 3. Mere-Baverstock-Harnham Hill faultline. 4. Remnants of the Mio-Pliocene peneplain. 5. Remnants of the Pliocene marine plain. 6. Summits rising to the marine plain level. 7. Base-levelled surface at *c.* 350 feet. 8. Eocene outcrop. 9. Escarpment of the *quadratus* Chalk. 10. Escarpment of the Chalk. 11. Escarpment of the Malmstone. 12. Escarpment of the Portlandian. 13. Escarpment of the Corallian. 14. Contours of the sub-Eocene surface at 100-foot intervals. 15. Contours of the dip-slope of the *Micraster* Chalk at 100-foot intervals.

That this is not a structural surface is indicated by the fact that in the transverse direction it shows no relation to the well-marked underlying syncline, and that in the longitudinal direction it passes on to successively older horizons in the Chalk as one proceeds westwards. At its extreme eastern end it is not improbable that the zone of *Marsupites* is represented above Grovely Wood. At the western end on Whitesheet Hill it passes across the Chalk Rock on to the Middle Chalk. These relations to structure are rendered even clearer by consideration of the neighbouring uplands.

Immediately to the south lies the Vale of Wardour and on its opposite side rises what is perhaps the most stately of all the Wessex escarpments. From its crest the ground falls away fairly quickly on its farther side into the Ebble valley. This slope is very nearly a true dip-slope, for although the dip seems small enough when reckoned in degrees (of the order of 2°) it amounts to a fall of about 200 feet per mile. This marked gradient of the dip-slope serves admirably to reveal the narrow bevel of the crest, most noticeable at the salient points of the escarpment. The bevelled crests fall eastwards in evident parallelism with the eastward fall of the Great Ridge on the opposite side of the vale. From 766 feet at the western end the descent to 600 feet above Burcombe Ivers takes about 7½ miles. This decline might actually be due to structural causes, since the scarp is slightly oblique to the strike. That this is not the case is shown by the fact that the Malmstone at the scarp foot falls from 500 feet to less than 250 feet between the same points, so that the thickness of the overlying Chalk is growing steadily from west to east, and the crest-line itself is passing on to successively higher horizons in the Chalk in this direction.

A third ridge of generally east-west trend, and almost as large as the Great Ridge itself, lies on the southern side of the Ebble valley. At its eastern end this ridge is actually developed upon the axis of the anticline of Bower Chalke, but for most of its length it is, like the last, of cuesta form with a north-facing escarpment. It, too, shows the same gentle fall from west to east and the same bevelled crest-line. The latter feature is well developed in the western part of the ridge where it forms the high ground at 700 feet to 850 feet north and west of Ashmore. The undulating plateau-like character of this facet of the cuesta contrasts strongly with the much more strongly inclined structural surface – actually the dip-slope of the *Micraster* Chalk – which underlies the immediately adjoining areas of Cranborne Chase and Vernditch Chase.

These three ridges of markedly contrasted structure – respectively, synclinal, homoclinal and anticlinal – thus exhibit the common feature of bevelled summit areas which decline gently eastwards. If points at corresponding altitudes on each ridge be joined, the resulting contour lines run smoothly across the map and may be taken as, at any rate, a first approximation to the contour lines of the Mio-Pliocene peneplain from which the ridges have been carved. Moreover, the drawing of these generalized contours upon a map brings to light other points belonging to the plain whose relation to it might otherwise have been overlooked.

A prolongation of the 600-feet contour which runs by way of Codford Circle across the Great Ridge near Grovely Lodge and so by Burcombe Ivers to Knighton Hill, passes in another 4 or 5 miles through the summit of Pentridge Hill. This bold and isolated hill lies well removed from the high ground so far considered and rises abruptly from the low downlands of North-East Dorset within a few miles of the main Eocene outcrop of the Hampshire Basin. Its steep northern face is

actually the escarpment of the Belemnite Chalk; its gentler southern slopes carry a series of Eocene outliers and are obviously a dissected portion of the sub-Eocene surface. The most northerly of the outliers, some 3 miles from the main outcrop, caps the actual summit at a height of 600 feet. It is difficult to avoid the conclusion that this summit also is little below the surface of the Mio-Pliocene peneplain, and that the latter here passed on to the Tertiary formations. The relation between the two surfaces whose intersection was schematically represented by White more than thirty years ago can here be given precise expression. The sub-Eocene surface is declining in a southerly direction at an angle of 30°E. at approximately 120 feet per mile. In the opposite direction we rise from 600 feet at Pentridge to 691 feet at Marleycombe Hill above Bower Chalke in 3 miles, giving a gradient of 30 feet per mile. The older surface is thus tilted along this particular line of section four times as steeply as the newer one.

Pentridge, however, is not the only point on the plain brought to light by the generalized contour lines. In connecting points on the ridges on the two sides of the Vale of Wardour it was found that several points within the vale fall on or close to the lines so drawn and at the appropriate altitudes. They occur on the crests of the escarpments of the Malmstone and the Portlandian Beds, but, owing to the high dips prevailing, their extent is in all cases small. In the western part of the vale, Cleave Hill (700 feet) and Haddon Hill (737 feet) developed on Malmstone near West Knoyle, continue the summit plain at the 700-foot level from the Chalk right across the major fault which forms the northern boundary of the vale. Farther south-east, two other points on the Malmstone rise to 700 feet and Stop Beacon culminates at 778 feet. On the southern side of the vale the Malmstone scarp again rises to the appropriate level, here about 800 feet, in conformity with the greater altitude of the Chalk downs north of Cranborne Chase, and on the road between Shaftesbury and Semley station it shows some signs of bevelling. No point in the Portlandian outcrop actually attains the presumed full altitude of the summit plain, although in rising to 700 feet (2 miles west of Tisbury) it is perhaps only 70 feet short of it. Farther east a similar relation to the plain is shown by the culminating points of the Malmstone outcrop, notably at Castle Ditches and Wick Balls, but in spite of their present defect of altitude it seems just to regard these summits as having conformed to the general level in the fairly recent past. It is to be remembered that the extent of hard rock upon which they depend for their preservation is strictly limited, and unlike the case of some of the plateau-like Chalk ridges the smallest recession of the escarpment is attended by a notable loss in the altitude of the crest.

From this discussion it would thus appear that we may recognize surviving remnants of the Mio-Pliocene peneplain over a considerable area in South Wilts. and Dorset. Their total area is admittedly small, but the area in which the former existence of the plain seems satisfactorily demonstrated is not less than 200 square miles. Throughout this region the plain shows complete independence of structure, bevelling all the Mid-Tertiary flexures indifferently. It truncates the powerful anticlinal axis of the Vale of Wardour, the subsidiary axis of Bower Chalke and the synclines of Hindon, the Ebble valley and the Great Ridge. It is quite unaffected by the presence of the powerful strike fault of Mere. It must originally have bevelled all horizons from the Kimmeridge Clay to the Eocene, and it is still preserved on the chief hard or permeable rocks of this sequence – the Portlandian, the Malmstone and the Upper Chalk. Finally, it is intersected on

Pentridge Hill by the sub-Eocene surface dipping toward the Hampshire Basin with a gradient at least four times that of the summit peneplain itself. In no other part of South-East England can the Mio-Pliocene surface be satisfactorily recognized over so large and continuous a tract of country and its relations to the Mid-Tertiary flexures so convincingly demonstrated. We may perhaps even go so far as to regard it as in some sense a type locality, the more so since it not only furnishes evidence regarding the present form and structural relations of the summit plain, but also as to its original character. We have already noticed that the drifts which cap some of the summits may possibly be regarded as portions of the regolith of a sub-aerial peneplain, and a little evidence pointing also to the sub-aerial character of the surface is furnished by the detail of its present form.

At the western end of the Great Ridge the plain attains a height of 784 feet, on Whitesheet Hill, where it is interrupted by the main Chalk escarpment. Rising from the Malmstone dip-slope beyond, are the Lower Chalk outliers of Little Knoll and Long Knoll. The former, and the greater part of the ridge of Long Knoll rise just over 800 feet and appear to be detached remnants of the summit plain, but at the western end of Long Knoll the ground rises in about 200 yards, smoothly but quickly, to 945 feet. This final eminence can hardly be part of the plain, being marked off from it by slopes of 10°–20°. If the plain be of sub-aerial origin this rise is best explained as a residual hill some 120 feet high; but if the plain be marine it must be regarded as an unconsumed stack or island. In the latter case it might be expected to show signs of marine cliffing, but, in fact, the thinly covered Chalk slopes pass down smoothly into the remainder of the ridge. A mile or so away the larger masses of Brimsdown Hill (933 feet) and Cold Kitchen Hill (844 feet) appear to be similar residual eminences rising slightly but definitely above the peneplain. Similar relations are again found in the area north of Cranborne Chase where Melbury Hill (863 feet), Breeze Hill (859 feet), Win Green (911 feet) and Winkelbury Hill (852 feet), appear as the culminating points of subdued but definite rises above the plateau. Individually they might perhaps be passed over as 'accidental'; but taken together they are too numerous and too systematically disposed upon hard rocks or watersheds to favour this hypothesis; they are residual eminences rising from a sub-aerial peneplain.

From our type locality on the southern border of Wiltshire the Mio-Pliocene peneplain may be traced along the Chalk uplands, north-eastwards to the Chilterns, eastwards to the Weald and south and west into Dorset and Devon. In the first-named direction we note that the surface fringes the whole north-western margin of Salisbury Plain. The latter is a synclinal area whose upturned rim has been bevelled at altitudes between 650 and 750 feet, but mature dissection in the present cycle has made the bevel very difficult to appreciate except in the large view. Farther east, in the Downs of northern Hampshire the summit peneplain forms fairly large upland areas, readily distinguished from the marine Pliocene bench at about 650 feet, and rising with very gentle slopes to the broad swelling culmination of Walbury Hill (975 feet), the most elevated point on the English Chalk. It is difficult to say whether this high ground represents a residual hill rising above the general peneplain level or whether it should be regarded as a gentle convexity induced by the warping which let in the Pliocene sea. The gentleness of the slope perhaps favours the second suggestion. It is quite otherwise, however, with the culminating points of the Chalk which overlook the Vale of Pewsey from the north. Here without doubt we have a series of residual hills of subdued but well-defined

form which rise 100 feet or so above the general level of the plain, here at 750–800 feet. It is reasonable to suppose that they mark the line of the old watershed between the drainage to the North Sea, via the Kennet, and that to the Channel, via the Avon.

In the Marlborough and Berkshire Downs the summit plain is readily inferred although little of it remains. It is represented to-day only by the long convex and often undulating crests of the finger-like downland ridges. These are generally united only at their north-western extremities where they attain altitudes of 900 feet or more. Generalized contours permit us to infer that the plain declined gently south-eastwards to the 700-feet level, at which altitude a visible feature on most spurs separates the summit surface from the Pliocene marine bench. Similar relations exist in the Chilterns, where in spite of the even more restricted development it is possible to mark off with some precision the area occupied by the Mio-Pliocene peneplain. To-day it comprises merely the narrow convex crests of a series of branching ridges at 650–850 feet, in a zone only two or three miles broad lying immediately behind the scarp crest between Watlington and Luton. The contrasts of form, drainage--pattern and superficial deposits between this zone and the adjoining zone of the Pliocene abrasion platform are here excellently displayed (p. 56).

In and around the Weald all the higher ground, say above 700 feet, may be referred to the Mio-Pliocene peneplain. The North Downs from the Medway gap westwards to Dorking rise well above the level of the Pliocene marine bench, and just as in the Chilterns this higher ground may be regarded with some certainty as part of the sub-aerial peneplain. Behind this portion of the Chalk cuesta, the Greensand outcrop just rises to the peneplain level in Ide Hill near Sevenoaks, while in the western Weald, Leith Hill (965 feet), Hindhead (895 feet) and Blackdown (918 feet) indicate the elevations to which the peneplain rises over the Central Wealden axis. There is good reason for supposing that along the western and southern margins of the Weald the higher parts of the Chalk upland from Holybourne Down near Alton southwards by Wheatham Hill to the South Downs and so east to the Arun also represent the peneplain surface. Butser Hill which rises to 889 feet is probably a low residual rising slightly above the old plain. The peneplain is again represented farther east by the crest of the Downs between Washington and Plumpton, and in the Isle of Wight by the crests of the Southern Downs and of the upland south of Calbourne.

We have now traced the Mio-Pliocene peneplain continuously across southern England from the margins of the London Basin, where it is dated by the fossiliferous deposits left upon its down-warped surface by the transgressing Pliocene sea, to the western limits of the Cretaceous uplands. Considering its development over South-East England as a whole it is seen that it shows no broad regional variations in altitude such as would suggest tilting as a whole in one direction or another. Rarely, if ever, does it descend below 700 feet, or rise to 900 feet, though residual eminences may stand 100 feet or so higher than the plain itself. In contrast to this general uniformity of altitude, however, we find perceptible gradients ranging from 10–40 feet per mile in the plain within each of the regions studied. The gradients vary considerably in direction and very commonly decline toward the main lines of existing drainage. These facts taken in conjunction with the not infrequent occurrence of the low residuals rising above the general level convey a strong suggestion as to the origin of the surface with which we are dealing. These

are clearly the characters of a sub-aerial peneplain in which base-levelling, though far advanced, was not complete even upon rocks as soft as the Chalk. It is in entire conformity with this conception that, when we try to trace the peneplain westwards into the regions of harder rocks, we find it to be more limited in extent and increasingly interrupted by unreduced residuals. Thus, in the Mendip region, the inlying areas of resistant Old Red Sandstone rise above remnants of an upland plain which may well be the representative of the Mio-Pliocene peneplain. In the South-West Peninsula the peneplain must be represented by one of the high-level platforms fringing the uplands of Dartmoor and Bodmin Moor. It is probable that if we were able to trace the peneplain into the Welsh massif we should find it reduced to the status of a high-level valley bench, representing merely an important stage in the history of valley excavation.[26]

CHAPTER V

THE PLIOCENE TRANSGRESSION AND ITS INFLUENCE ON LANDSCAPE DEVELOPMENT

(i) THE PLIOCENE DEPOSITS

The only considerable mass of marine strata accumulated within our area after the Miocene planation is found in the Pliocene deposits of East Anglia. As a whole they evidently represent an extension of the immediate ancestor of the North Sea on to the present mainland of Britain. The earliest member, the Coralline Crag, was believed by Harmer to have accumulated in a channel which 'opened southwards or south-westwards across some part of South-East England'. If such a channel existed it was closed by uplift early in the succeeding phase of the Red Crag. The several divisions of the Red Crag group themselves in horizontal rather than vertical sequence, showing the relation known as 'imbricate off-lap', with the younger divisions towards the north. Harmer inferred a progressive tilting movement which gradually raised the southern part of the Crag area into land, while submerging the country farther north. The conditions were those of a series of sandy bays; as the earlier bays were silted up and raised, so the coastline retreated progressively towards the north. The Norwich Crag sets in suddenly north of Aldeburgh and thickens northward. Its formation marked a further stage in the retreat of the North Sea coastline. The beds are marine but they are regarded as essentially the off-shore deposits of the western edge of the Rhine delta. The succeeding Weybourn Crag may mark a slight readvance of the sea, but the Cromer Forest Bed at the top of the Pliocene series undoubtedly represents a return to fluviatile or deltaic conditions. By this time the whole of the southern part of the North Sea must have been land or delta-marsh. It is believed that the ancestor of the Thames joined the Rhine in a widespreading confluent delta.

The Forest Bed is succeeded at Kessingland by the Westleton Shingle, which is also found above the Norwich Crag and beneath the earliest of the proved glacial deposits near Norwich. It is a marine shingle of Early Pleistocene age and we shall find that its presumed equivalents far to the west afford us an invaluable datum in interpreting the physiographic chronology of the London Basin.

The East Anglian Pliocene beds represent a sequence of events contemporary with that with which we are concerned in the inland areas, and as such the main features of the record have an obvious relevance to our enquiry. It is evident, however, that this region stands widely apart from the rest of South-East England in the mode of its evolution. If we regard the Miocene peneplain as an approximation to the actual, or potential, sub-Pliocene surface, we are confronted with marked differences in the level and general relations of this surface (Fig. 11). Throughout Wessex and the Weald, and along the Chiltern edge as far east as Hitchin the surface in question lies near the 600-feet level. But in North-East Essex the sub-

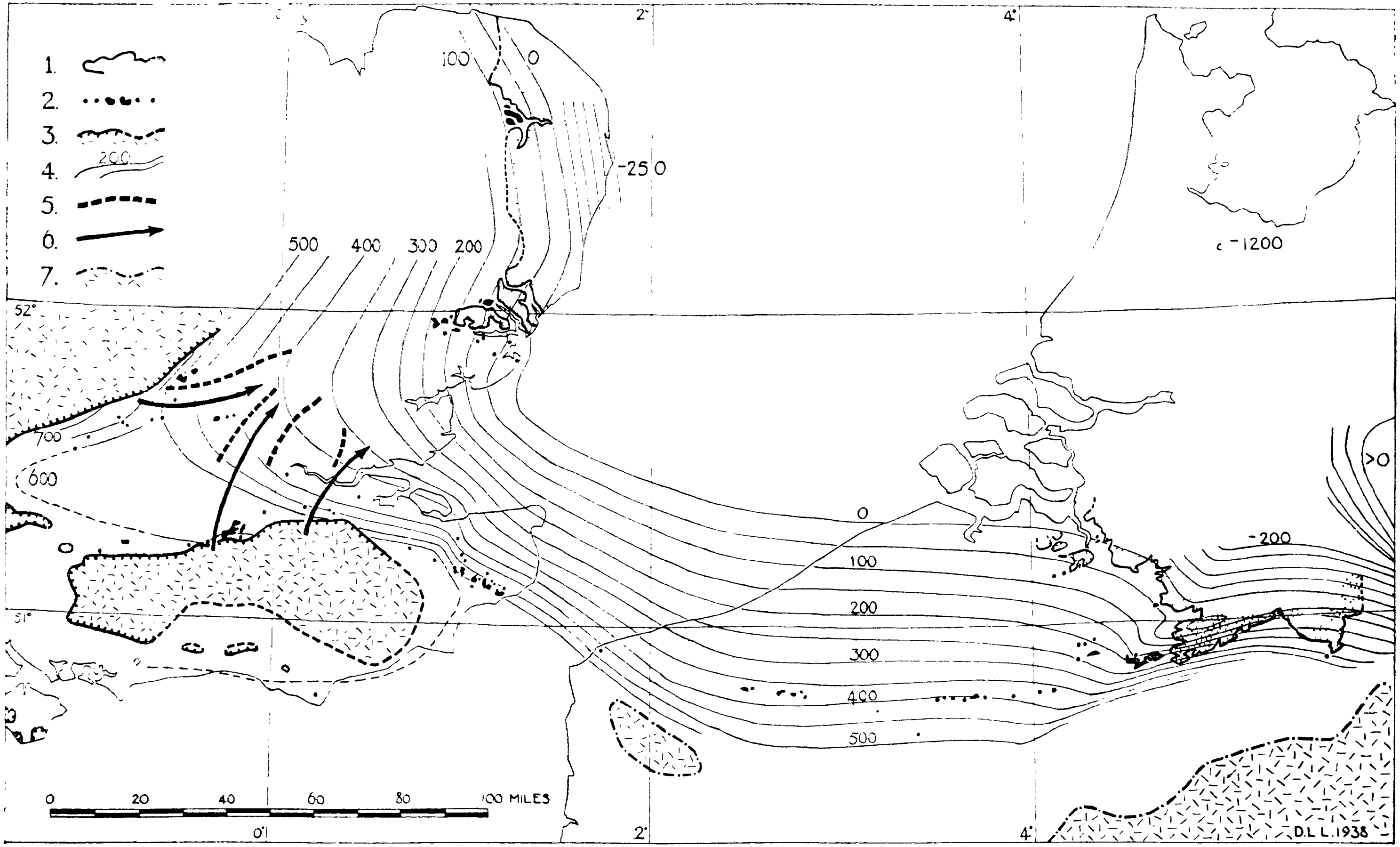


FIG. 11 – The Geography of the Pliocene Epoch. 1. Main Pliocene outcrops. 2. Pliocene outliers. 3. Pliocene shoreline feature and its presumed continuations. 4. Contours of the Pliocene base at 50-foot intervals; heights in feet. 5. Pebble Gravel facies-boundaries. 6. Streams supplying Pebble Gravel constituents. 7. Generalized 650-foot contour in France and Belgium.

Crag surface is at about 60–70 feet O.D., and it declines northwards to —200 feet O.D. at Lowestoft. Considered over a wider field the Pliocene base plunges even deeper. At Utrecht it is at about —1,200 feet O.D. and at Amsterdam it must be lower still. Therefore, if we assume a quasi-horizontal initial position for the Miocene peneplain, it is clear that it has been uplifted in the west, and depressed below sea-level in the east. Whether we are to regard this as the result of a widespread tilting or a more localized flexure somewhere in the Essex region is a question to which no ready answer can be given. We shall discuss some evidence bearing on the matter below. It is certain, however, that in the regions surrounding the North Sea a downwarping movement, concurrent with sedimentation, was proceeding during Pliocene times. The form of the Pliocene base as inferred by Harmer[27] between Yarmouth and Groenlo suggests a truly geosynclinal condition. There is, of course, abundant evidence that the North Sea Basin existed as a subsiding area filling steadily with sediment from Cretaceous, possibly even from Permian times, onward. The facts noted above enable us to trace the further evolution of the North Sea 'downwarp' during Pliocene times and it is clear that the sedimentary filling of the trough is even yet incomplete. The main significance of this for our enquiry lies in the fact that the north-eastern portion of our region, marginal to the North Sea depression, has shared in the growth of that depression, suffering a periodically renewed eastward or north-eastward tilting until a very recent date. Over the rest of the south-eastern region no such movement took place, as will be fully demonstrated in the sequel.

Although no Pliocene deposits older than the Coralline Crag are known in East Anglia,* the equivalents of the Coralline Crag in Belgium and Holland rest upon the ferruginous sands and sandstones of the Diestian stage. Underlying the main mass of Pliocene deposits in Holland, they rise southwards and westwards reaching sea-level between Ostend and Heyst, and elevations of 400 feet at Cassel and 500 feet in outliers on the Chalk near Calais. Apparent equivalents of these Diestian Beds were discovered as long ago as 1857 at Lenham in Kent, where sands are piped into the face of the Chalk escarpment and have evidently been let down by solution from a level at or above the escarpment crest. Pertaining also to the Lenham Beds are certain outliers of sand at elevations between 450–600 feet on the plateau of the North Downs near Folkestone.

The Kentish Lenham Beds appear to form a natural continuation of the Diestian Beds of Flanders, occurring at similar elevations and in the same general topographic relation to the surrounding country. We might therefore be tempted to draw a provisional Diestian coastline south of Lille and Lenham, beyond which we might swing it northwards across Essex to pass westward of East Anglia. Such a reconstruction would represent the Diestian coastline as the farthest southward extent of the Pliocene 'bay' of the North Sea – a bay whose northward retreat in later stages we have already traced. It is, indeed, possible that the Diestian sands did not extend much farther than this, but we have the clearest evidence of the former presence of a Pliocene sea much farther west and shall show, indeed, in the sequel that it passed over much of South-East England. For this conclusion there is direct geological evidence, but morphological evidence of a wide Pliocene trespass is even more striking and widespread.

* The basal conglomerate of the Coralline and Red Crags preserves evidence of an older and possibly pre-Pliocene formation in the fossiliferrous 'boxstones'.

For many years outliers of sand and shingle have been known on the North Downs in situations comparable with those in East Kent. For a time they were confounded with the Eocene deposits, but it was ultimately shown that they were distinguishable petrographically from the latter. Moreover, at Netley Heath near Guildford, casts of marine fossils were found belonging to genera present at Diest. During the last thirty years, a large number of small outliers of these beds have been recognized along the North Downs, in similar positions on the Chiltern Hills and at a few points within or on the margins of the Eocene tract of the London Basin. It was at first supposed that all the beds were of Diestian age, but re-examination of better preserved fossil remains at Netley Heath proved that the fauna there was of Red Crag age and a similar fauna has been obtained from relict blocks at Rothamsted (Herts). It is possible, therefore, that we are dealing with the deposits of a transgressing sea, younger in the west than in the east; that there was, in fact, a marked Pliocene transgression, prior to the retrogression whose course we have briefly traced. Many of the purely geological points at issue hardly concern us here, however, for there can be no doubt that the outliers are the remains of a once continuous sheet of sand and shingle – a true formational unit in the broad sense. This fact is established not only by the petrographic unity of the deposits, but by the striking uniformity in elevation and physiographic situation shown by the outliers. The most compelling arguments for a former widely extended Pliocene sea in South-East England are, indeed, morphological. It can be shown that the beds everywhere rest on a well-marked platform which is bevelled across the inclined Chalk and Eocene rocks. This platform can be recognized over wide areas where the formerly overlying beds have been removed or redistributed. With its aid we can reconstruct the coastline of the Pliocene marine episode, and by a study of its present attitude we can form an estimate of the nature and extent of post-Pliocene warping. While the landscape thus throws light on a past geological episode, it is equally true to say, and more germane to our present enquiry, that an appreciation of the nature of the episode is necessary to the understanding of the landscape, from the standpoint of both geomorphologist and human geographer. We shall therefore trace in some detail the distribution and relations of the Pliocene bench.

(ii) THE PLIOCENE PLANATION AND COASTLINE FEATURES IN THE NORTH DOWNS AND CHILTERN HILLS

We shall treat in order the several blocks of the North Downs, falling between the water-gaps of the transverse rivers.

1. In East Kent, between the Stour Gap and the coast, the Pliocene outliers rest on a well-marked surface cut in Chalk which declines gently northward at about 20 feet per mile. This surface completely bevels the Chalk escarpment over a belt about 10 miles broad. The northerly limit of the 'bevel' is marked approximately by the line of the Canterbury-Dover road, beyond which the Chalk country reveals the form of a true dip-slope, i.e. the surface is essentially that of the sub-Eocene plain. Near the escarpment the Pliocene beds rest on the Middle Chalk. Northwards they overstep the Upper Chalk and beyond the line of the Dover-Canterbury road they must have passed on to Eocene beds. Since the most southerly of the outliers rests upon the very crest of the escarpment it is evident that the deposits must formerly have extended well beyond it into the Wealden

tract and we have no means of placing the shore-line of the time. If, however, the dip of the Chalk be assumed to have remained unchanged south of the escarpment, the Pliocene base must have passed on to the Gault about six miles from the present escarpment.

2. A very striking physiographic change takes place at the line of the Stour gap. Westwards the escarpment ranges on for more than 20 miles to the Medway with a singularly level crest-line at a height of 620–625 feet. Though the Pliocene beds are only obscurely exposed in this tract, the bevelling of the Chalk escarpment is still plainly recognizable; but the bevel is narrow, not extending down the dip-slope beyond the 600-feet contour. The greater part of the latter shows a simple and regular northward inclination at about 100 feet per mile, while the dip of the Chalk base between the escarpment and Bobbing is about 150 feet a mile. There is no doubt therefore that the general surface of the main dip-slope marks the sub-Eocene surface, overstepping the Chalk southwards. The bevel is too narrow to give clear evidence of its inclination, and there are no Pliocene outliers in the country to the north, which would allow us to calculate the sub-Pliocene gradient. It is apparent, however, that as in the country farther east the Pliocene shore-line must have lain south of the escarpment, and if we assume that the gradient of the sub-Pliocene surface did not differ materially from that proved east of the Stour, the Chalk must have been over-stepped about three miles from the present escarpment line. Northwards the sub-Pliocene surface must have passed on to Eocene rocks close behind the present Chalk escarpment and to this cause its subsequent complete demolition is to be attributed.

3. West of the Medway gap a further striking change takes place in the form of the Chalk dip-slope and the relations of the Pliocene beds to it. Between Folkestone and the Medway gap the crest of the North Downs shows little variation in height, though on the whole it climbs very slowly westwards. West of the Medway gap a relatively steep westward ascent begins. Near Wrotham Hill the crest-line attains a height of 700 feet for the first time, and ignoring the notches produced by the consequent valleys, the ascent continues to Botley Hill (882 feet) the culminating point of the North Downs. Westward the crest drops again, though it remains above 700 feet as far as White Hill, Caterham, and exceeds this level in isolated tracts beyond, at Colley Hill, Reigate, and Betchworth Clump (Fig. 22).

No Pliocene beds occur near the crest of the escarpment in this area, except at its western extremity at Headley Heath. In their place are found Eocene outliers (Blackheath Beds), as at Holly Hill, Stanstead, Knockmill and Nore Hill (Worms Heath) and elsewhere south of Caterham. The presence of these outliers of incoherent sand and shingle indicates that the Pliocene sea never washed this part of the Downs. It is true that many of the masses are piped into the Chalk, but nevertheless in many cases they give rise to definite features, forming steep-sided hillocks. These could hardly have escaped obliteration by the waves of the Pliocene sea. Pliocene outliers occur, however, lower down the dip-slope, and although the escarpment is not bevelled, the marine abrasion platform seen in East Kent is plainly traceable as a bench cut in the dip-slope. Its features may best be appreciated by reconstructing the form of the dip-slope by means of generalized contours which ignore the deeply cut dry valleys produced by later dissection. The general relations may best be followed by tracing the relatively steep rise at the back, i.e. south of the Pliocene bench. This we regard as representing a veritable degraded cliff marking the line of the Pliocene coast.

East of the Darent gap the steepest declivity occurs between the 650 and 600-foot contours. North of the latter the gradient flattens and there is some evidence of probable Pliocene relics at Ash (550 feet) and Cobham (400 feet) in the country to the north. In both cases the sub-Pliocene bench was cut in Eocene rocks, and as in the country around Lenham it has been almost completely destroyed by later erosion. Similar conditions persist for some miles west

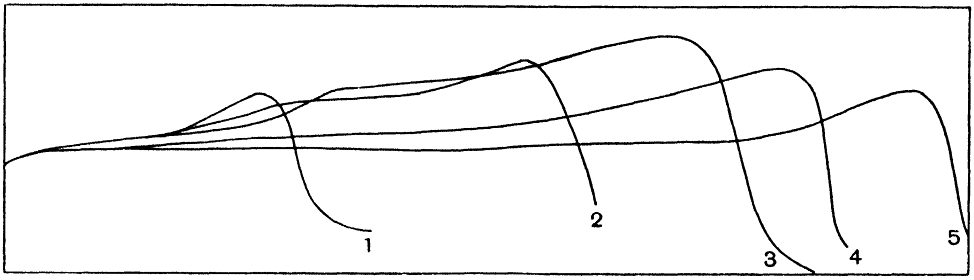


FIG. 12 – Profiles (diagrammatic) of the North Downs to show Pliocene planations – Section lines: 1. Through Well Hill. 2. Near Cudham. 3. Near Botley Hill. 4. Through Sanderstead. 5. Through Burgh Heath.

of the Darent gap (Fig. 12); the slope between 650 and 600 feet is steep and there is a flattening at its foot. Northwards lies the Pliocene outlier at Well Hill (550 feet), resting on Eocene beds and it is again evident that the width of that part of the bench cut in Chalk was small. Near Cudham and westwards to Biggin Hill and Tatsfield a slight change in the relations is apparent; there is a steep descent from 850–750 feet, a flattening thence to the 700-foot contour, followed by a steep descent to 650 feet, and a further flattening below it. We have therefore signs of an upper bench at about 700 feet, while the main or lower bench is backed by a rise at a slightly higher level than in the country to eastward. The upper bench, if such it be, quickly fades out, however, and from the apex of the salient of high ground near Botley Hill and westwards as far as the Merstham gap the steep descent takes place between 750–650 feet, with a well-developed bench north of it. West of the Merstham gap, there occurs the best development of the Pliocene bench in Surrey, the conditions recalling those of East Kent. The usual steep descent behind the escarpment-crest occurs at Colley Hill, Reigate, but the surface flattens out into a conspicuous platform three miles broad, extending northwards to Burgh Heath and Banstead. Over this flat Pliocene sands and shingle are widely spread, resting partly on Chalk and partly on Eocene beds. At Headley Heath similar relations are seen, the back-slope descending from 750–650 feet, and the Pliocene deposits deposits coming on above the 600-foot contour and extending some distance below it. Proved Pliocene outliers occur farther north on the borders of the Eocene outcrop at Sanderstead (500 feet) and Shooters Hill (424 feet).

The variations in the form of the 'cliff' or back-slope over an east-west range of 16 miles between the Darent and Mole gaps are illustrated in Figs. 12 and 22. This makes it quite clear that the variations are not due to tectonic disturbance; in all cases the upper slopes flatten to a platform at 550–600 feet, which shows no sensible change of level throughout the area. The variations in the form of the back-slope, as reconstructed, result partly from inevitable ambiguity in the run of the generalized contours, but we believe that they represent to a very large extent

veritable though partly obscured details of the Pliocene coastline. The apparent occurrence of an upper bench near Cudham is particularly notable as suggesting marine planation at two levels.

At Headley, the Pliocene coastline has swung back close to the escarpment edge, and it appears that it crosses that line again near the Mole gap. At Ranmore, the escarpment is bevelled once again and it shows a similar form at Netley Heath. Between these places, the crest-line of the escarpment again exceeds 700 feet for a short distance and the outliers near Pigdon lie well to the north, suggesting another northward projecting salient in the coastline. The relations in this tract, however, are not entirely clear; much of the country is thickly wooded and the steeply inclined sub-Eocene surface comes far up the dip-slope.

West of Netley Heath the crest of the Downs decreases rapidly in height and nowhere reaches the level of the Pliocene bench until it has crossed the Hampshire border, 20 miles to the west. The large Pliocene outlier on the Hale plateau, west of Aldershot, maintains the chain of evidence however. Here the beds occupy an isolated situation, resting on Eocene sands and there is no trace of the platform in the immediately surrounding country. The beds can be traced even farther in a westerly direction, but we shall defer discussion of this until after the Chiltern area has been treated.

The Pliocene outliers of the Chiltern tract are less numerous and less well exposed than those of the North Downs, but the bench on which the deposits rest is developed with relations precisely similar to those we have noted in Kent and Surrey. This is immediately apparent in the Berkhamsted area. The outlier at Littleheath, the first to be discovered on the Chilterns, lies towards the frontal edge of a prominent shelf, which extends north-westwards across Berkhamsted Common and is backed by sharply rising ground behind the escarpment edge at Ivinghoe

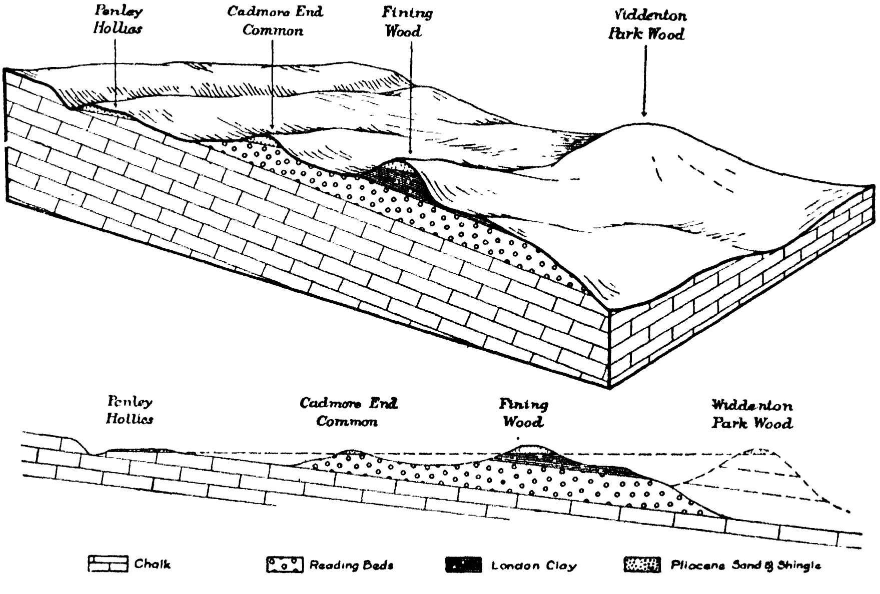


FIG. 13 – The Relations of the Pliocene Shelf on the Chiltern Hills.

Beacon. This 'back', the presumed coastline feature, is, indeed, far more continuous and conspicuous in the Chiltern area than in the North Downs, being traceable from near Goring gap to beyond Luton, a distance of over 30 miles. It is clearly portrayed on the old hachured maps of the Ordnance Survey, as well as on the maps of the 5th Relief Edition (Sheets 95, 106) in which the original hachures are combined with contours at a 50-foot interval. The general relations of the Pliocene shelf and of the outliers that rest on it are indicated in Figs. 13 and 16. It is broadest in the area east of High Wycombe, where the surface descends from above 800 feet near the escarpment crest, flattening at about 650 feet and extending thence to elevations of below 600 feet in a distance of four to five miles. Southwards the Eocene outliers at Penn, Coleshill and Cowcroft are all capped by Pliocene shingle at about 500 feet.

From this central area of broadest development the bench narrows towards the north-east, bearing on its surface the outliers of Littleheath and Gaddesden Row. Beyond Luton, it is still recognizable, though much dissected. It is not traceable beyond the Hitchin gap, for in East Herts and North-West Essex the escarpment is much lower and covered with glacial deposits (p. 114). Westwards, the bench and the 'back' behind it are clearly traceable to the neighbourhood of Lane End, where its features have recently been studied. The Pliocene deposits here transgress visibly from Chalk on to Eocene beds. Beyond, the 'back' is traceable by means of the sharp declivity between the 700-foot and 650-foot contours past Ibstone, Northend and Park End to Nuffield. In front of it the bench was here cut almost entirely in Eocene deposits and traces of the Pliocene beds are found on nearly all outliers of the latter. We regard the small shingle outlier at Greenmoor Hill (600 feet) as the most westerly of the Chiltern Pliocene outliers.

It may be noted that, in the southern regions, Pliocene outliers occur on the margin of the main Eocene outcrop at Sanderstead and at Shooters Hill. North of the Thames the only comparable outcrops are those of Bushey Heath, Elstree and Arkley, where Pliocene shingle caps the highest summits (504–465 feet O.D.) of the London Clay country of the Middlesex-Hertfordshire boundary. They have generally been included as part of a younger formation – the Pebble Gravel, described in the sequel, but Barrow recognized that they were in some measure distinct from this and petrological examination of the associated sands confirmed their attribution to the Pliocene series.[21]

(iii) SUMMARY OF RELATIONS IN THE LONDON BASIN

As far west as the longitude of Reading the extent of the Pliocene sea is thus attested by geological and morphological evidence alike. In seeking to trace the sea still farther west we are forced at present to depend on morphological evidence alone and we may therefore profitably pause at this point to gather the conclusions arising from a study of that part of the region where the evidence is fullest. They may be stated thus:

1. The marine abrasion-surface on which the deposits rest is traceable on both sides of the London Basin. It is easily recognizable and continuously developed, subject to later dissection, even where all trace of the former cover has been removed. It owes its preservation to the pervious nature of the Chalk which, owing to the secular drop of the water-table, concurrently with recession of the bounding escarpments, has been left in a state of arrested dissection. Where the sub-Pliocene

surface passed on to the weaker and generally less pervious Older Tertiary (Eocene) beds it has been almost completely destroyed.

2. The Chalk dip-slopes bounding the London Basin conform to one of two types, according as the sub-Pliocene surface bevels the crest of the escarpment or forms a bench cut in the dip-slope and backed by higher, more steeply sloping, ground (Fig. 14). In east and central Kent and again near Guildford, in Surrey, the scarp-crest is bevelled. This was the feature noted by Topley and probably also by W. M. Davis who interpreted it, in common with other hill-top bevelling in the

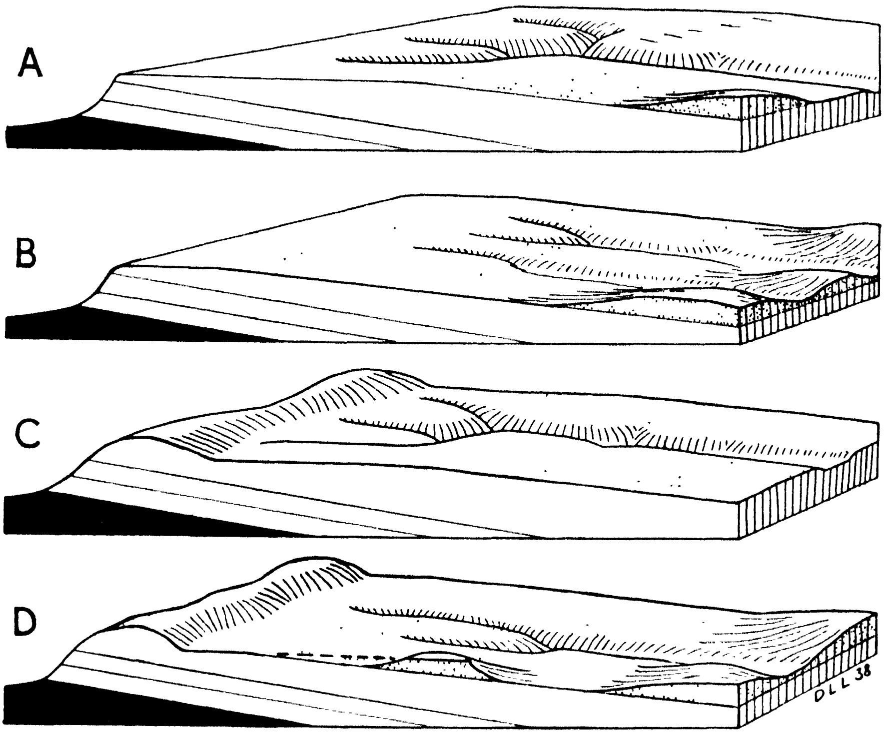


FIG. 14 – The Form of the Dip-Slopes surrounding the London Basin. A. East Kent. B. Mid-Kent and West Surrey. C. East Surrey, West Kent and Chiltern Hills. D. West Kent and Chiltern Hills. Front sections show strata below the Chalk, black; Lower, Middle and Upper Chalk, white; Eocene, stippled. Block surfaces show the sub-Pliocene plane, white; sub-Eocene plane, dotted.

region, as evidence of sub-aerial planation terminating a cycle of erosion. In West Kent and eastern Surrey, i.e. in the area immediately south of London, and again throughout the Chiltern region between Goring gap and Hitchin, the upper limit of the sub-Pliocene surface (*circa* 650 feet O.D.) is some distance from the escarpment crest, the ground rising fairly steeply towards the latter. In such cases it is clear that the actual Pliocene coastline is preserved as a degraded cliff or strand-line feature and an area of the unsubmerged country survives on the landward side. Where the summit bevel exists, as in Kent, the coastline evidently lay beyond

the present escarpment and has disappeared in the course of recession of the latter. It becomes clear that the Pliocene sea near London was a gulf or channel co-axial with the London Basin and roughly co-extensive with it (Fig. 15). It was, in fact, simply the latest expression of an older tendency for the Basin to subside and admit the sea from the great geosynclinal tract of the North Sea, lying eastwards. The Pliocene shelf occurs on both sides of the Basin and can be recognized also over at least one small area of the central tract of Eocene rocks (Fig. 15).

3. The question of the nature and amount of the post-Pliocene uplift is one that not only concerns the problems of palaeo-geographic restoration, but bears directly on the mode and rate of evolution of the present landscape forms. Since the Pliocene shelf and the surviving outliers upon it maintain an essentially constant elevation from East Kent to North-East Hants, a distance of roughly 100 miles, it is at once apparent, as was first clearly recognized by Bury,[28] that there has been no intra- or post-Pliocene warping of the Wealden area along transverse axes. The same conclusion is valid for the northern flank of the area between the Lambourne Downs and the Hitchin gap. The North Downs crest rises to its culminating point at Botley Hill (882 feet) while the Chiltern crest culminates at 852 feet between Wendover and Princes Risborough. A line joining these two points runs from N.W.–S.E. through the western outskirts of London and it seems reasonable to suggest that the crest-levels of the Chalk escarpments reflect slight *pre-Pliocene warping* along this axis, which is close to the older axis of cross-warping in the London Basin (p. 5). It is notable that the Pliocene sea was narrowest near this line.

Though no post-Pliocene transverse warping is indicated, the inclination of the Pliocene shelf on both sides of the Basin towards the centre raises the question of longitudinal warping. The existing sub-Pliocene gradients, however, must necessarily include both the original gradient of the Pliocene sea-floor as traced away

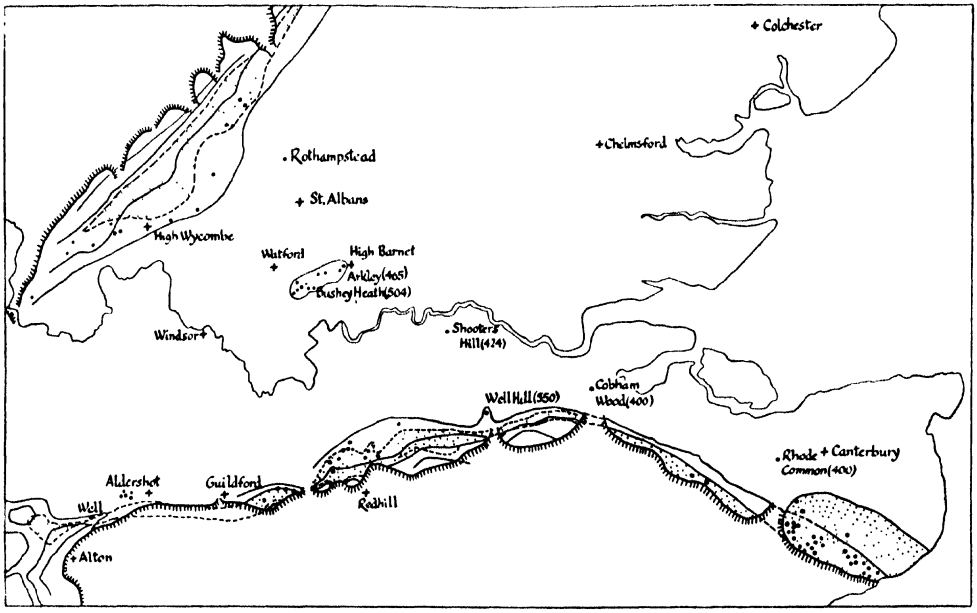


FIG. 15 – The Pliocene marine features in the London Basin. Pliocene outliers, dots. Pliocene shelf, stippled. Approximate positions of 500-, 600-, 700- and 800-foot contours shown.

from the shore-line and any gradient imposed by later warping along longitudinal axes. Available data do not permit any accurate separation of these two constituents of the gradient. Of one thing alone can we be certain – viz. that any late tilting of the area has been extremely slight; it is a generous estimate to assign half the observed gradient to such a cause and in all probability it was less than this. If we accept such a figure we have a means of evaluating the successive folding movements which went to form the London Basin and the Weald. As we have seen, the Eocene base oversteps the Chalk zones, thus giving us a measure of pre-Eocene movement. Similarly a comparison of the inclination of the Eocene and Pliocene basal planes indicates the relative magnitude of the pre- and post-Pliocene stages of growth. On the south of the London Basin the dip of the Eocene beds varies within somewhat wide limits. If we base our calculation on the conditions in Kent, the Chalk base has an inclination of about 150 feet per mile, the Eocene base 100 feet per mile and the Pliocene base 20 feet per mile. Assigning half the last named to the category of original gradient the three stages of tilting in order of age are represented quantitatively by the figures 5 : 9 : 1. The sub-Pliocene plain on the north side of the London Basin is much less steeply inclined and the amount of subsequent tilting included can hardly exceed 5 feet per mile. In the western Chiltern area the inclination of the basal planes of the Upper Chalk and the Eocene rocks are approximately 80 feet and 60 feet per mile respectively. The relative magnitude of the successive tilting movements are thus represented by the figures 4 : 11 : 1.

4. More immediately interesting to the geographer is the fact that, since the Chalk terrains around London are genetically composite, they are susceptible of most significant regional sub-division. The full development involves three zones: (a) a crest-region, part of the former Pliocene land-surface; (b) the sub-Pliocene facet; and (c) the sub-Eocene surface, tilted by the Mid-Tertiary folding, and stripped of its over-burden of Eocene rocks. The physical characteristics of these three facets are necessarily different. On a geological map all three are shown as underlain by Chalk with or without a superficial covering of residual 'Clay-with-Flints' and associated loams, etc. In fact, however, the variations of superficial cover commonly defy the methods of general geological mapping, though they can be forecast within limits from the considerations now before us. The crest-regions have been exposed continuously to the atmosphere since the early Tertiary emergence of the region. It is here that we should expect, and, in fact, actually find, the greatest development of true residual Clay-with-Flints. The sub-Pliocene bench was exposed much later, when the marine deposits were removed. Over wide areas traces of these deposits remain at least in sufficient bulk to modify soil conditions and true Clay-with-Flints is absent or subordinate, though the surface covering is often mapped as such. The sub-Eocene surface is still younger in respect of exposure to the atmosphere, for after the emergence of the Pliocene sea-floor, not only the Pliocene cover but a thick mass of Eocene rocks had to be removed. Here true Clay-with-Flints is absent, though Eocene outliers in all stages of demolition survive and the soil characters are often modified by the distributed residuum of these beds.

It is probable that work now in progress on the soil-profiles of the regions will demonstrate even more definitely the consequences of different durations of exposure and leaching on these three surfaces, but pending the completion of such work the reality of the soil differences is not in doubt. It is strikingly reflected in

the maps of the Land Utilisation Survey which show, for example, in East Kent that the sub-Eocene facet is a region of dominantly arable farming, while the sub-Pliocene surface is in pasture and woodland; the contrast, in French terminology, is essentially that between 'champagne' and 'bocage'. This relation is traceable with only local variations throughout the North Downs. The sub-Eocene facet is not so well developed north of London, owing to masking by glacial drift, but here it is evident that the improved land (now largely in pasture, but formerly in arable) extends over the sub-Pliocene facet, giving place to wide stretches of heath, scrub and woodland in the crest regions beyond the Pliocene coastline.

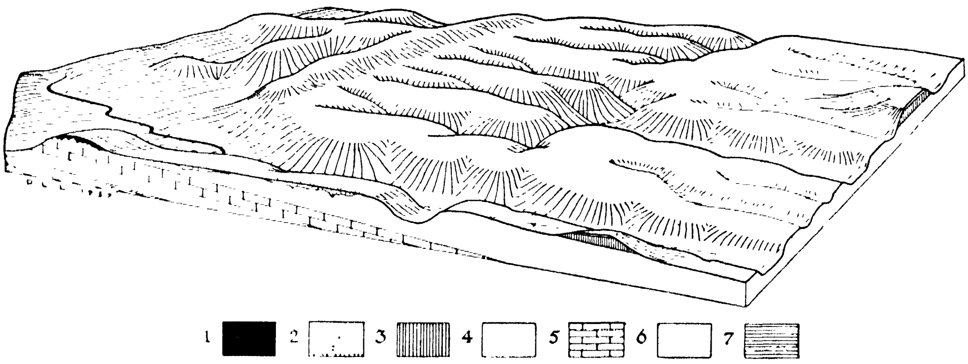


FIG. 16 – The three facets of a fully developed chalk cuesta: Mio-Pliocene land surface; Pliocene marine bench; and exhumed sub-Eocene plane. 1. Residual Clay with Flints. 2. Pliocene marine deposits. 3. Eocene clay and sand. 4. Upper Chalk. 5. Middle Chalk. 6. Lower Chalk. 7. Gault clay. Approximate dimensions of block: 8 × 16 miles.

5. The contrast between the three facets of the Chalk dip-slopes is well marked also in respect of texture and depth of dissection, and drainage pattern. This is perhaps most clearly seen in the central Chiltern area, immediately north-west of London. The main consequent affluents of the Thames draining from the Midlands had, of course, been established long before the Pliocene transgression; but, as Davis concluded, their number was reduced by capture during the earlier cycle of erosion. The successful survivors must have entered the Pliocene sea and on the emergence of its floor they extended themselves across it. Contoured maps of the area demonstrate at a glance that on the landward side of the Pliocene coastline the main consequent rivers receive lateral tributaries. On the seaward side, however, such tributaries are virtually absent, but the wide interfluvial plateaux are scored by a series of independent sub-parallel valleys – now largely dry. These evidently represent a new series of consequent streams arising on the emergent sea-floor and heading near the old coastline (Fig. 16). Beyond the latter the lateral tributaries of the main rivers have eaten back into the interfluves so as to reduce them to narrow crests flanked by combes running S.W. and N.E. This is a most characteristic feature in the morphology of the Chiltern crest-region, well seen near Ivinghoe, and both east and west of the Wendover wind-gap. We may state the relation alternatively by saying that there is a minor watershed near the old coastline separating areas in which the trend of the smaller valleys is in directions inclined nearly at right angles to one another (Fig. 16).

The contrast in drainage pattern is not everywhere so marked as in the central Chilterns. In the North Downs, south of London, the coastline feature itself is well marked, but the drainage of the Pliocene land was evidently by small streams entering the sea almost normally to the coast. In the western Chilterns (beyond the Wye Valley) there is no evidence of any drainage lines on the Pliocene land; but the consequent drainage of the emergent sea-floor has extended itself by headward erosion into the former land area. In neither case, therefore, do we find a sharp change in valley direction at the former coastline, though in the former there are small changes in direction which are certainly significant. The general contrast in topographic form remains valid, however, wherever areas of pre- and post-Pliocene drainage are adjacent. The minor valleys of the former Pliocene land are always wider and deeper and the interfluves approximate to razor-back form. In a word, the landscape is fully mature while that of the sea-floor region is still in a state of youthful or sub-mature dissection. This relationship is as well displayed in the Caterham district of Surrey, as in the central Chilterns.

(iv) THE WESTERN EXTENSIONS OF THE PLIOCENE SEA

With one exception, noted below, no Pliocene outliers are at present known west of a line joining Greenmoor Hill and the Hale Plateau, but the consistency of physiographic relations shown by the deposits and the platform on which they rest in the region east of this line encourages the search for evidence farther west. It is evidently to be expected that the features traceable in the western Chiltern area should continue on the Berkshire Downs. The latter tract is much dissected, presenting, indeed, marked and significant contrasts to the Chiltern Hills in its general morphology. There is no doubt, however, that the Pliocene 'back and bench' is here preserved. The former is traceable from near Farnborough to Lambourn Woodlands and considerable relics of the platform exist around Catmore, Brightwalton and Poughley, north of Hungerford (Fig. 17). Westwards, the 700-foot contour converges rapidly on the line of the River Kennet and beyond Marlborough the Pliocene bench is so much reduced as to have the aspect merely of an old high-level valley floor. Virtually the whole of the Marlborough Downs thus lies beyond the old Pliocene coastline and presents the largest stretch of the Mio-Pliocene land surface still remaining in the Chalk uplands north of the Thames. The same features of texture of dissection, form and drainage that were seen to characterize the remnants of this surface in the higher Chilterns are found again here on a more extended scale, and are again in sharp contrast to the coarser and less mature dissection, and the simpler and less integrated pattern of drainage which are exemplified on the lower portions of the dip-slope. The Pliocene shoreline here divides the Chalk upland into parts of roughly equal size, but contrasted aspect, which the geographer must regard as regionally distinct.

On the south side of the Kennet Basin we have already observed that the zone of denuded periclines which forms its border has features which suggest that the whole belt of country from Kingsclere to Savernake Forest suffered planation at about the 600-foot level (see p.30). Remnants of the bench are still to be seen along the whole length of the Woodhay inlier, and below Walbury Hill, backed by a steep rise to 900 feet or over. It is seen again bevelling the Chalk that margins Savernake Forest, and possibly in the summits of the highest of the Eocene outliers there, while south-west of Marlborough it is developed over a considerable tract of the Chalk; it is possible that deposits of the expected type may come to light here.

The highest portions of this shelf just fail to attain 700 feet, and are sharply marked off from the ground beyond, which rises sharply from 700 feet to over 900 feet. The shore-line is thus marked approximately by the 700-foot contour in this neighbourhood and we see that this converges on the Kennet from both sides, leaving room only for a river entry from the west. This is the head of the Pliocene Gulf.

Evidence of any other western extensions of the Pliocene sea of the London Basin must evidently be sought in the neighbourhood of Basingstoke and Alton – i.e. between the Kingsclere Downs and the Upper Hale outlier near Aldershot. In 1922, Bury[28] included with his description of the Hale outlier a brief notice of a further mass of sand and shingle of the same character, five miles to the south-west near the hamlet of Well. Here the deposits rest on Chalk just below the 600-foot contour, but probably extend above it. Their western continuation, if any, must be sought north of the high ground which culminates in Holybourne Down (728 feet). There is, in fact, a flat-floored embrasure or col in the Chalk hills around Herriard. The elevation of its floor is 550–600 feet, and we have no doubt that a portion of the sub-Pliocene surface is here represented. We are thus led to envisage a narrow opening through which the Pliocene sea may have passed into the region of the Test Basin. The great Church Oakley gap, west of Basingstoke certainly represents another and larger opening in the encircling Chalk Downs, through which the Pliocene sea passed into the Wessex area. A feature undoubtedly to be identified with the Pliocene shelf extends along the whole of its northern margin and may be traced thence westwards across Hampshire and into Wiltshire. Thereafter it becomes discontinuous, but may be recognized widely in regions even farther west, but a full discussion of the implications of this evidence is best deferred until a later stage (see p. 65).

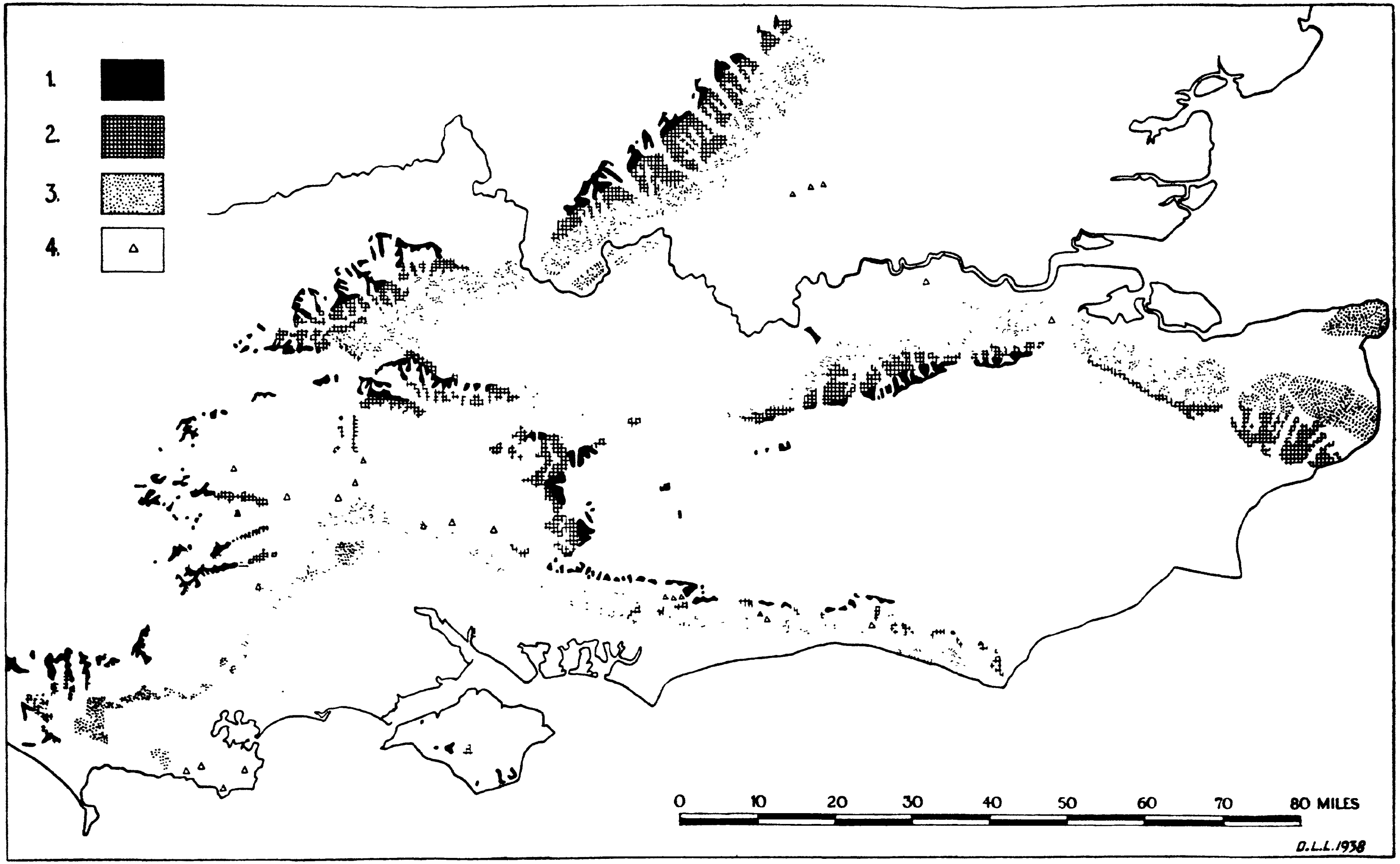


FIG. 17 – Present day Distribution of the Remnants of the Principal Planation Surfaces of the Chalk Uplands of S.E. England. 1. Mio-Pliocene peneplain. 2. Pliocene marine plain. 3. Exhumed sub-Eocene surface. 4. Summits rising to the level of the marine plain.

CHAPTER VI

THE EVOLUTION OF THE WESSEX RIVERS

(i) INTRODUCTION

The earliest coherent views as to the origin of the rivers of southern England took shape early in the second half of the nineteenth century as a natural corollary of the growing belief in the efficacy of sub-aerial erosion. The Wealden escarpments, once thought of as marine cliffs, were then recognized as the work of rain and rivers, and as early as 1862 J. B. Jukes, in an appendix to his famous paper on the rivers of southern Ireland, tentatively asked 'whether the lateral river valleys which now escape through the ravines traversing the ruined walls of the Chalk that surround the Weald may not be the expression of the former river valleys that began to run down the slopes of the Chalk from the then dominant ridge that first appeared as dry land during or after the Eocene period'.[17]

This view was taken up at once by Ramsay, and in the second edition of his *Physical Geology and Geography of Great Britain* he invoked the waves of the sea to 'shave across' the country and produce a slightly inclined plain, and 'river denudations' to carve the present scenery from that plain after it had been uplifted. The capacity of the Wealden rivers to excavate the lowlands within the escarpments while cutting down the valleys that traverse them was demonstrated beyond argument by le Neve Foster and Topley in 1865,[29] and when Topley wrote his *Geology of the Weald*, in 1875, the theory of the Wealden rivers seemed complete. He visualized them draining from a simple east-west uplift in the Central Weald northwards and southwards across gently sloping plains upon which the outcrops of hard and soft rocks had already been laid bare in concentric outcrops. True, he said nothing about when the marine plain was formed, or about the date of its uplift, but later geologists came to think of the arching of the Weald as a broad result of the Mid-Tertiary movements.

When W. M. Davis[19] argued so cogently in 1895 that the 'shaving across' of the Wealden outcrops required by Ramsay and Topley might have been the work of rain and rivers in an earlier cycle of erosion, it was not realized that this change of viewpoint introduced difficulties into the problem which the older theory of the marine plain had avoided. Mackinder,[30] writing in 1902, was prepared to suggest with complete indifference that 'either by the action of the weather, or perhaps by marine erosion during a period of partial submergence the (Wealden) dome was planed down, so that the strata lying beneath the Chalk were exposed'. Such a view fails to appreciate that the rivers that would be inherited from a surface produced by sub-aerial denudation from the folded and uplifted surface of Mid-Tertiary times would not possess the simple and direct pattern of those formed by the gentle tilting of the marine plain. The Mid-Tertiary movements did not produce the simple domed structure so commonly assumed. The powerful longitudinal folds and faults described in Chapter III must surely have given rise

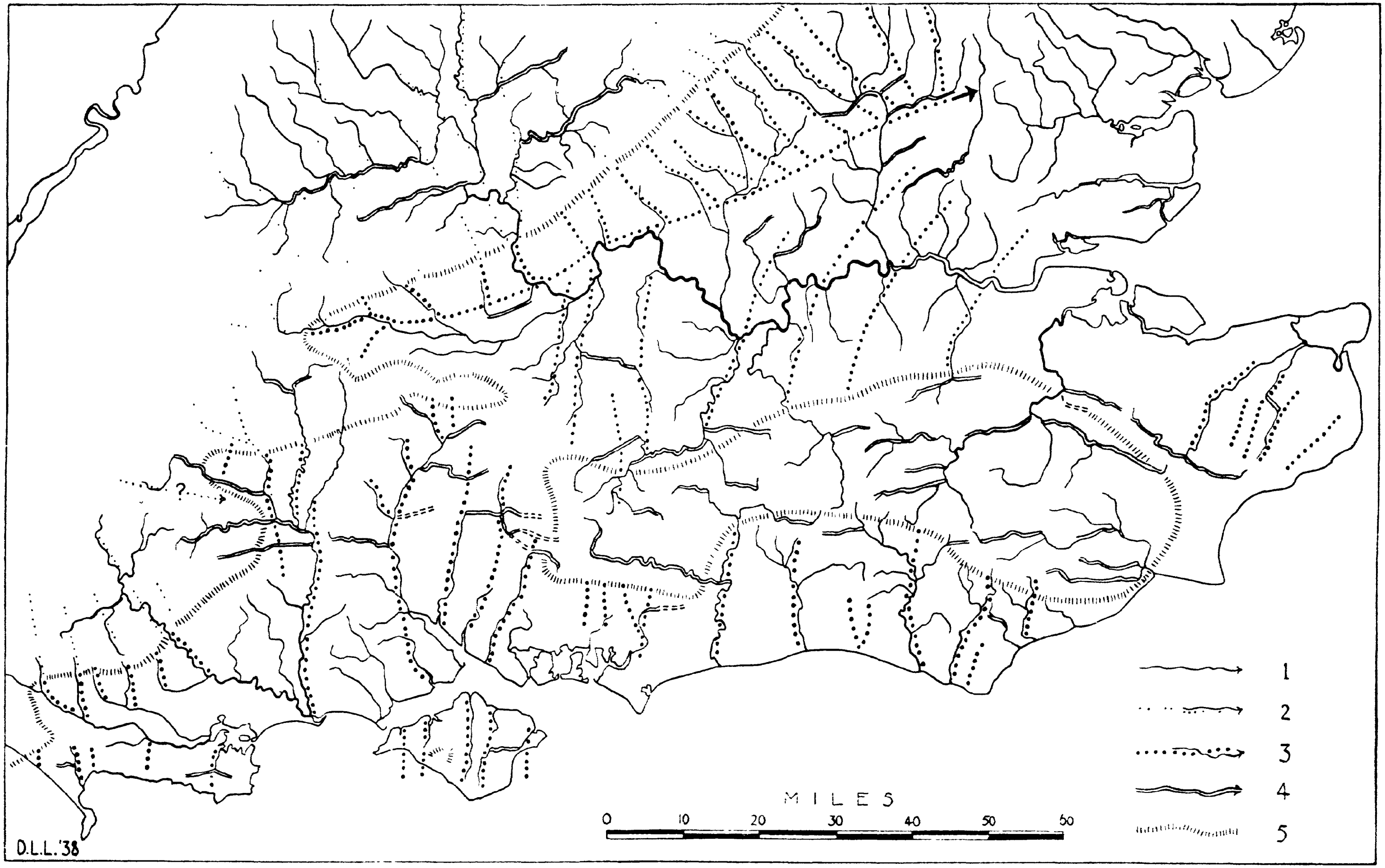


FIG. 18 – Some Elements in the Drainage Pattern of Southern England. 1. Existing streams. 2. Presumed courses of consequent streams of Mid-Tertiary cycle. 3. Presumed courses of consequent streams of Late Tertiary cycle. 4. Streams adjusted to structure. 5. Inferred margin of Pliocene land area.

to a drainage system of predominantly longitudinal type which must thus have differed widely from the present simple radially divergent plan. It is remarkable how little attention has been given to this disconcerting fact. Bury is the only worker who has considered its implications, and he was led, largely on this ground, to suggest that the drainage of the western Weald originated on a plain of marine denudation cut across the longitudinal flexures long after the folding. We now know that such a surface was provided in the London Basin by the emergence of the Pliocene sea-floor and it is also certain that the Pliocene sea entered the Wealden area at more than one point. Did it once spread over the entire Weald, obliterating the former drainage, as Bury was tempted to conlude, or did it trespass locally and in limited fashion, leaving the greater part unsubmerged, so that the drainage is now in its second cycle of development? If the truth lies somewhere between these extremes, by what means may we seek to delimit the submerged from the unsubmerged area? The purpose of this chapter is to propound a solution to this problem. It does not yield readily to frontal attack, but may be outflanked by a study of the behaviour of the Wessex rivers. To these we shall first turn and in the light of the information they afford we can reach important conclusions as to the Wealden drainage.

(ii) THE DRAINAGE OF WESSEX

The drainage of Wessex is much less generally known and its problems have evoked much less discussion than is the case with the Wealden rivers, but it yields nothing to them in either interest or importance in our present enquiry. Broadly speaking, it is a centripetal system draining toward a longitudinal trunk stream which is now dismembered but which formerly flowed along the general axial line of the Hampshire Basin from west to east in much the same way that the larger London Basin is drained to-day by the Kennet-Thames. These two major streams – the former Frome-Solent River and the modern Kennet-Thames – flowing in parallel eastward courses have their territories separated by the longitudinal watershed which runs broadly from west to east, across Wessex and the Weald. It is immediately noticeable that this watershed is very differently placed in the two regions. Whereas in the Weald it occupies an approximately central position so that the drainage of this uplifted tract is shared in roughly equal proportions by the streams draining northwards and southwards, in Wessex its position lies far to the north so that virtually the whole of Wessex is drained toward the Frome-Solent and the English Channel. To this fact, indeed, Wessex owes much of its geographical and historical unity, as various writers have recognized. The morphological significance of this northward position of the water-parting, which lies in its relations to structure, has, however, passed almost unnoticed. Yet it at once springs into prominence when we observe that Wessex is the true structural continuation of the Weald. We should surely regard it as anomalous if the south-flowing Wealden streams like the Adur and the Ouse were observed to take their rise at the line of the North Downs and flow in simple and direct courses across all the structural complexities of the Central Weald before they reached the English Channel. Such, however, is the character of the Wessex rivers and herein lies the major problem which they present.

a. *The Origin of the Southward Flowing Streams*

Some of the more evident discrepancies between the courses of individual rivers in Wessex and the folds of the region were, of course, noted many years ago,

particularly by H. J. Osborne White in the several district memoirs published by H.M. Geological Survey. White noted how in the Chalk region of Central Hampshire, the two principal streams, the Itchen and the Test, flow southward in strikingly discordant fashion across anticlinal folds at Winchester and Stockbridge respectively, 'at points where the relative vertical displacement of the strata amounts to several hundreds of feet'.[31] (Fig. 19). Similarly he noted how one of the headwater streams of the Itchen, namely, the Candover Brook, and a neighbouring stream, the Meon, also effect remarkable transections of important longitudinal folds.[32] These folds all raise considerable upland ridges of Chalk athwart the

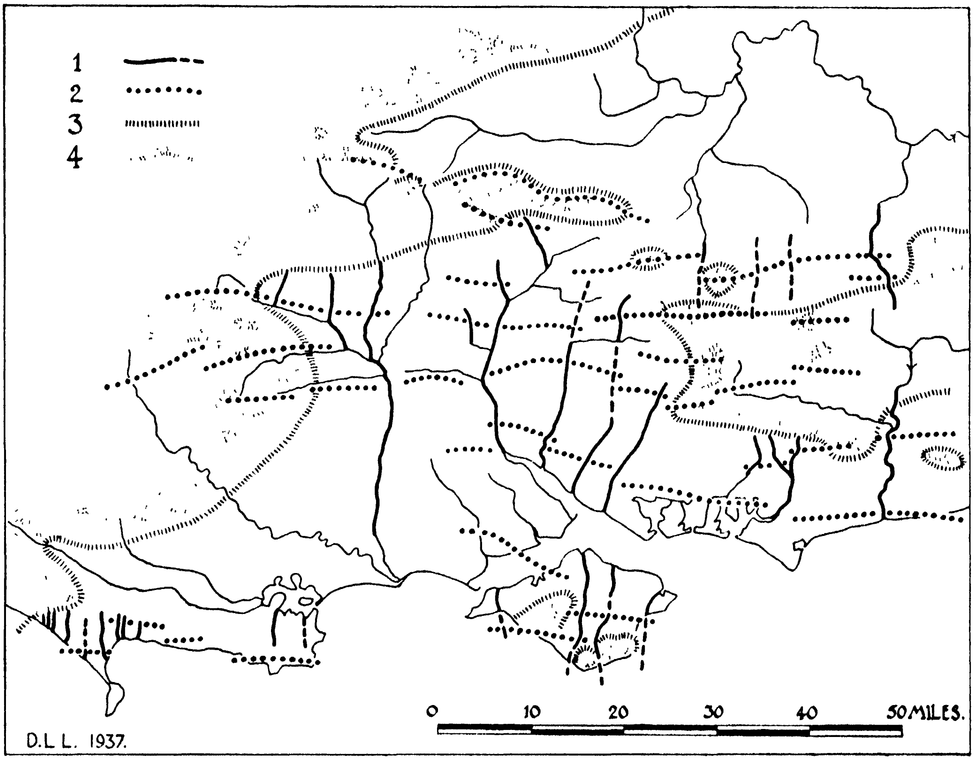


FIG. 19 – The discordant relation between streams and structure in the Wessex region. 1. Discordant portions of existing or reconstructed streams. 2. Anticlinal axes. 3. Suggested position of the Pliocene shoreline. 4. Surviving remnants of the Mio-Pliocene peneplain.

paths of the streams which cut through them in steep-sided and restricted passages. Other examples of the same sort of discordant relations between streams and folds may be noted in the same area. West of the Test, the little Wallop Brook cuts a course across the Stockbridge axis parallel to that of the larger stream, although at a point where the amplitude of this fold is admittedly much reduced; and in the neighbourhood of Salisbury the Avon and Till cut right across the eastern end of the Warminster anticline, which is still strong enough to bring the Middle Chalk to the surface in the Till valley at Stapleford, and to reveal Chalk of the *cortestudinarium* zone at Woodford in the valley of the Avon.

The problem of the relations between streams and folds in this region as a whole may best be realized if we consider the character of the drainage system to which these folds must have given rise. We have already seen that it is possible to portray the folds of northern Wessex by means of contours for the top surface of the Chalk after deformation (*supra* pp. 16 and 20, and Fig. 5). This surface is, of course, not the one upon which the Miocene rivers took their rise, but we may presume it to be sufficiently like to allow us to draw conclusions as to the nature and pattern of that river system. The tectonic map shows clearly how the Wealden folds continue westwards across Wessex with but little abated vigour, although the fold belt as a whole is nothing like so elevated as in the Weald. At the time of uplift these longitudinal upfolds would all throw off short and steep streams which were doubtless gathered by longitudinal consequents flowing along the intervening synclines in the direction of axial pitch. Such streams would, in fact, constitute the major arteries of the drainage, and considerable transverse elements would occur only where the drainage of one longitudinal trough spilled over into a neighbouring syncline by a low tectonic col or saddle. Cases of this sort, however, were probably few, and actually, of all the existing streams, only the Test in its exit from the Alderbury-Somborne syncline avails itself of such a situation. A single such outlet moreover would suffice to carry away the combined waters of all the streams flowing into the Andover depression, and such evidence as is available strongly suggests that this outlet was by way of the Church Oakley syncline and so northwards into the London Basin.[33]

Whether this last contention be accepted or not, it is clear that a contrast, already sufficiently remarkable, exists between the Miocene drainage which was consequent upon the folding episode, and the main elements in the drainage pattern of to-day. The former system was essentially longitudinal; the present one is essentially transverse, comprising large trunk streams flowing discordantly southward across fold and outcrop to join the one important longitudinal river of Wessex – the now dismembered Frome-Solent. Such a wholesale and systematic disregard for structures, maintained by the streams over a wide area can surely be ascribed only to an origin upon a surface on which these structures had no expression. This might imply one of two things: either, that the discordant elements in the Wessex drainage had been given their present directions by uplift and tilting of the sea-floor at some time before the Mid-Tertiary folding; or else, that they came into existence where the folds were either planed off, or buried, or both, so that they could have no possible influence upon the stream courses. The first hypothesis is, in fact, to suppose that the anomalous streams are antecedent. This view may be dismissed from present consideration as being inherently unlikely and in such a case impossible to demonstrate. The second involves us in believing that the visible relations between streams and folds are due to some form of epigenesis.

It might at this point be asked whether the discordances between streams and structures could not be explained as the results of modifications of an original drainage pattern by river capture. Attempts have, indeed, been made to explain individual discordances in this way. Osborne White made a plausible case in 1910 to explain the crossing of the Warnford axis by the Meon, but, in the same discussion, found the relations of the Candover Brook to the Stockbridge fold 'less readily to be accounted for'.[32] There is moreover reason to think that the arguments used in the case of the Meon are not valid in other cases of exactly the same kind.[33]

Indeed, drainage rearrangement by capture is essentially a piecemeal process, a matter of individual instances; and although circumstances can readily be conceived in which captures may occur in related groups or sequences, it is impossible to imagine conditions in which such a large number of streams should have been diverted from stable synclinal positions, and induced to take discordant courses through upstanding ridges of resistant Chalk. The changes involved must surely have resulted in a loss and not an increase in the degree of adjustment of streams to structures, and so run quite contrary to the general rules governing such phenomena.

Yet the very argument which proves to be such a stumbling block to the hypothesis of capture is, on the other hand, a strong witness in the case for epigenesis. While it is difficult to conceive of a series of captures, even in the early stages of the first erosion cycle, which would systematically abolish the longitudinal drainage elements and replace them by regularly spaced, transverse, streams, the features of the present drainage are all expectable corollaries of epigenesis. Superimposition of drainage is a regional phenomenon imposing a broad regularity of spacing and uniformity of direction upon all the streams of a considerable area, and offers at the same time a single explanation of all the inconsistencies that have been noted between drainage and structure.

We have therefore felt bound to accept the view that the streams of northern Wessex from the Hampshire Meon to the Wiltshire Till are not those which originated as a result of the Mid-Tertiary folding, but a later series initiated by super-imposition from a surface planed across these folds at some subsequent date. In the sequel it will further appear that the streams of South Dorset, the Isle of Wight and of most of Sussex show comparable features and must be of similar origin. The area over which epigenesis must be assumed is thus very wide. It comprises the whole terrain bordering the English Channel as far west as the Isle of Portland, and extends inland across Wessex to the western end of the London Basin. From that point northwards and eastwards we also find a superimposed drainage – the system that appeared with the re-emergence of the sea-floor after the Pliocene transgression. As has already been pointed out (p. 57) the western limits of the Pliocene sea beyond the London Basin have not been determined by direct evidence, but every available indication suggests that the waters passed beyond the limits of the Basin into the Wessex region. Such further extension of the Pliocene sea involves the very region in which we are confronted with evidence of an epigenetic drainage. Direct stratigraphical evidence of this further trespass of the Pliocene sea over southern England still awaits discovery. But morphological evidence corroborative of the testimony of the drainage systems may be cited from many parts of Wessex, and provdes at the same time clues which may lead to the discovery of relics of Pliocene sand and shingle which alone can furnish final conviction as to the truth of the hypothesis here adopted.

b. *The Pliocene Planation of the Wessex Uplands*

As in the London Basin the morphological evidence of the Pliocene trespass is found in the surface configuration of the upland tracts. Normally it takes the form of areas planed off by the waves of the Pliocene sea and backed, in favourable circumstances, by the shore-line feature marking off the slightly more elevated ground of the unsubmerged area beyond. Further, the gently undulating peneplain region is also distinguishable from the area planed by the sea, by the greater extent and maturity of its dissection. The survey of the Wessex uplands

from this point of view is admittedly still incomplete; but enough has been done to corroborate most emphatically the conclusions drawn from the drainage systems.

Mention has already been made (p. 58) of the bench feature which margins the Church Oakley depression and serves to mark the main water connection between the seas of the London Basin and Wessex. This upland bench may be traced westwards at heights between 570 and 650 feet from above Basingstoke along the south side of the Kingsclere Downs, and is well seen around Hannington and from Beacon Hill near Burghclere. It forms a conspicuous flattening on the long Linkenholt spur which projects into the Bourne valley, and beyond that valley has been traced along the southward slope of the Downs from Doleswood to Collingbourne Wood. Beyond the Avon, however, on the margins of Salisbury Plain, all trace of the feature is lost. The only areas high enough to carry any traces of the marine plane prove on examination to show little sign of it. Rather do they suggest by their rounded forms and mature (even if arrested) dissection, that sub-aerial erosion has been continuous here through two cycles. It is still possible, however, that all the southern and eastern parts of Salisbury Plain were submerged, the isolated Sidbury Hill (735 feet) rising as an island.

We have already seen that farther to the south-west the Mio-Pliocene peneplain bevels the ridge-tops on either side of the Vales of Wardour and Ebble, and that at the western ends the ridges rise slightly in low residual eminences, which remain as the last vestiges of the relief of the preceding cycle. This area was evidently not invaded by the sea, but it is likely that the rather flatter eastern ends of these ridges do, indeed, represent small surviving remnants of the area planed by the Pliocene waves. The crest of the Dorset Downs is of similar character. The surviving ridge-tops are well above 700 feet and belong to the undulating surface of the Mio-Pliocene peneplain, and it is not until we are as far west as Dorchester that we find any upland surfaces which, by their form and elevation, suggest that they were shaped by Pliocene marine abrasion. The uplands west of this town, however, are conspicuously flat at levels between 600 and 650 feet, and a recognizable feature marks the oncoming of slowly rising ground toward Eggardon Hill (828 feet) and the Hardy Monument (777 feet) or northwards toward the main escarpment.

These vestiges serve, despite their fragmentary character, to indicate the probable line of the Pliocene sea coast from the London Basin to the Channel (Fig. 19). Over most of Wessex, as over most of the London Basin, the marine plane must have been cut in the soft Eocene rocks and only locally, near the coast, was an abrasion platform cut in the more durable Chalk. In this formation, moreover, it seems to have been at best narrow, and is usually only a mile or two broad until we come to the coastal region of Dorset. This state of affairs contrasts strongly with the broad bench cut in parts of the Chilterns, in the North Downs of eastern Surrey, and especially of easternmost Kent where it attains a breadth of about eight miles. It suggests that the period during which marine erosion was operating in Wessex may have been shorter or that the waves possessed a shorter length of fetch than in the more easterly regions.

In the central part of Hampshire there were only a few restricted areas like the culminations of the Winchester and Stockbridge folds where the Chalk could actually have outcropped on the Pliocene plain, and planed areas of noteworthy size are therefore not to be expected. It is notable, however, that the highest summits on the Chalk ridges that mark these folds to-day are but little below the

600-foot contour from Cheesefoot Head near Winchester (579 feet) westwards to Salisbury, and this is consonant with the view that the marine plain crosses this area. North-east of Winchester an extensive upland surface can be correlated with the true marine plain. Extensive areas show little variation of altitude (from 690 to 650 feet only), appearing quite flat to the eye, and truncate the various zones of the Chalk from the sub-zone of *Echinocorys scutatus* down to the base of the Upper Chalk. This surface shows the immature dissection so characteristic of certain other surviving remnants of the Pliocene plain, and continues northward to the village of Farleigh Wallop where it overlooks the Church Oakley depression from the south. Eastward the ground rises generally toward the Weald, reaching over 800 feet in Wheatham Hill. A shore-line feature in this direction has not yet been traced, though we feel little doubt that the higher ground toward the scarp crest represents the westernmost extension of the portion of the Weald which remained unsubmerged.

c. *The Revived and Adjusted Rivers of Western Wiltshire*

In the preceding discussion of the Hampshire and Wiltshire rivers we noted that discordance between streams and structures was general as far west as the Till which drains part of Salisbury Plain. Beyond this point a longitudinal drainage is the rule, with one possible exception. This is provided by the little stream which drains from Imber Bottom, and the case is of sufficient interest to warrant special mention. The dry valley of Imber Bottom itself is essentially synclinal, flowing down the pitching western end of the trough which underlies Salisbury Plain. Three miles or so below Imber village it makes a rectangular bend and cuts its way out, against the dip, to the Wylye which is flowing roughly along the Warminster anticline. The two parts of the stream seem completely unrelated to each other and we may suggest that the upper part is a longitudinal consequent or resequent stream inheriting the trend of the Miocene drainage, while the lower and transverse half is epigenetic. The Till itself shows a similar composite character making an abrupt inflexion at Shrewton village, and it is possible that these sharp bends in the two valley systems actually mark points on the Pliocene shore-line – a conclusion quite consistent with that of the preceding argument.

The Vales of Wylye and Wardour are well known to be anticlinal, and the streams by which they are drained (Wylye and Nadder) cannot therefore always have occupied their present sites. It is possible to suppose, as did the Rev. W. R. Andrews[23] in the late nineteenth century, that they arose by the uplift and eastward tilting of a marine plain represented by the present ridge-tops of the region which they drain. We regard these ridge-tops, however, as parts of the worn-down land surface of the Mio-Pliocene peneplain and question whether the slight degree of tilting here associated with uplift would be adequate to dislodge any previously existing rivers from their courses. We conclude, therefore, that they are survivals from the Mid-Tertiary cycle and find confirmation of this in their adjustment to the major structures of the region, and the discordance of the Nadder toward the more resistant beds exposed during the present cycle. Originally we may imagine longitudinal consequents to have followed the synclinal axes of Salisbury Plain and the Great Ridge, but during the first cycle their short and steeply graded right bank tributaries unroofed the Chalk and Malmstone of the anticlines to lay bare the Gault below. On this a longitudinal subsequent drainage arose and, aided no doubt by the permeability of the Chalk, successfully ousted the original consequents from the role of master streams. Almost certainly this occurred before

the opening of the present cycle for no true fluviatile gravels have ever been recorded among the drifts of the ridge-tops. The process, however, may be seen in an arrested state in the Ebble valley, to the south (Fig. 10). This valley is actually synclinal, but in its upper part where the Chalk was most elevated and so first breached, the short right bank tributaries draining the steep northern limb of the anticline of Bower Chalke have opened up a series of scarp-rimmed depressions a mile or two in diameter, which have not yet become integrated into a single anticlinal valley.

Taken together these eastward-flowing streams of southern Wiltshire possess features which are in evident contrast to those characteristic of the streams farther east, and this contrast is strong evidence for the difference of origin which we have suggested. The one group is markedly transverse and seems best regarded as epigenetic and in its first cycle; the other is essentially longitudinal and has evolved by adjustment through two cycles of erosion. Between the two is the line, which on other grounds we should regard as marking the approximate position of the Pliocene shore-line.

d. *Subsequent Development in the Wessex Chalk Area*

Before leaving the rivers of northern Wessex something must be said of the course of drainage evolution during the present cycle in Central Hampshire, where the streams took their rise on the uplifted Pliocene sea-floor and coursed southwards to the Frome-Solent River. There appear to have been four such streams, parts of each being represented, from east to west, by the transverse courses of the Meon, Candover, Itchen and Test. For the most part their courses lay over Tertiary strata filling the Andover depression and the complex syncline that extends from the neighbourhood of Alresford to Salisbury and Wilton; the Chalk appeared only along the upfolds of Winchester and Stockbridge, though farther west in Wiltshire, its outcrop must have been continuous over the whole of Salisbury Plain. During the present cycle these streams have scoured out the Tertiary infilling from all these synclinal tracts, save only the deepest which lies between the Avon and the Test, and have made large inroads into the underlying Chalk, stripping the less resistant Belemnite Chalk from its harder basement of the *Micraster* zones. This removal of the softer rocks was accompanied by the growth of longitudinal tributaries along their outcrops. In this process some streams have been more favoured than others and a measure of drainage reorganization has consequently occurred. The Candover stream, for example, was early diverted by the subsequent outgrowth of the Itchen along the Eocene outcrop of the Alresford syncline, leaving the high level col at Lane End Down (across the ridge of the Winchester fold) a little below 500 feet. This capture is interesting in that the rate of growth of both the Itchen and Candover was determined by the rate at which they could lower their courses across the Chalk ridge of the Winchester anticline. The Itchen, paradoxically enough, was favoured by crossing the fold practically at its culminating point, for here the marine planation had already bevelled the fold and removed most of the hard Upper Chalk. Thus, in due course, when the softer Middle Chalk was exposed, downcutting was facilitated and the Itchen became the possessor of the Candover inheritance. It might, indeed, have collected the drainage of the whole of the synclinal tract behind the Winchester-Warnford upfold, but for the fact that the soft Tertiary infilling on which its subsequent feeders were extending did not survive long enough to permit the decapitation of the Upper Meon. With the disappearance of

the Tertiary clays and sands the stream courses became incised in the dry Chalk and migration of divides slowed down almost to a standstill. Later with the secular fall of the water-table resulting from the downcutting of the trunk streams, the lateral tributaries began to 'dry up' from the head downwards, and the Meon now abstracts water from the Itchen drainage by underground seepage from Bramdean Bottom.

An exactly similar story may be told of the encroachments of the Test. This stream was spared the necessity of cutting any gap through the Winchester axis, for it crosses that fold at a structural saddle from which the Tertiary cover is only now being removed. Consequently, although farther from the sea than the Itchen, it was able to cut a much lower gap through the Stockbridge fold at the latter place than could the Itchen at Wallers Ash. Thus the whole of the Tertiary basin beyond fell to its portion. The Itchen was decapitated by the subsequent Micheldever stream and its upper course is now wholly lost, being replaced by longitudinal streams fairly well adjusted to the synclines which they occupy. Here again, however, the Tertiary strata gave out before the integration of the drainage was complete, and just as the Itchen failed to capture the head of the Meon, so the Micheldever branch of the Test failed to capture the head of the Candover. The streams became incised into the Chalk and thus confirmed in their incompletely adjusted courses. A working example of this process can be seen to-day in the right bank tributary of the Test which drains the Alderbury syncline. Were this fold deeper, and the modern base level of erosion lower than it is, we might anticipate that it would stand a good chance of diverting the whole Salisbury Avon into the Test by this synclinal route. But already the Tertiary outcrop is much diminished and the larger part of the stream course is now established in the Chalk, so that its days of active encroachment are numbered. We may suspect too that the curious rectangular bends of the little Micheldever stream are due to a similar phase, in which it became incised, here to the north, and there to the south of the last considerable surviving relics of the Tertiary infilling of its synclinal trough.

The Eocene deposits have played a much smaller part in guiding the development of the Wiltshire rivers Bourne, Avon and Till. Only in the synclinal trough which runs beyond Salisbury to Wilton did such deposits actually outcrop either on the Pliocene plain or the Mio-Pliocene peneplain which bordered it; the remainder of the stream courses in Wiltshire ran over bare Chalk. As a natural consequence the three rivers became united in this tract to find a common outlet as the Lower Avon. In their upper courses the Avon and Till became incised deeply in the Chalk and have suffered little change, but it is likely that the Bourne is really only a remnant of its former self. A feature of the excavation of these valleys in the Chalk has been their discovery of the relatively advantageous conditions offered by the marly Chalk of the *Marsupites* zone as compared either with the *quadratus* Chalk above or the *Micraster* Chalk below. As a result of this difference of hardness these higher zones of the Chalk were stripped from the underlying *Micraster* Chalk over most of Salisbury Plain at a time when the watershed stood a hundred or so feet higher than it does to-day and that region possessed a system of actively eroding valleys. The Plain, as we see it now, is largely the exhumed, structural surface of the *Micraster* Chalk, dipping gently from north and south to the main synclinal trough and pitching to the eastward where it passes underneath the bold escarpment built by the overlying *quadratus* division. At the foot of this escarpment runs the Nine Mile River (tributary to the Avon) in the

north, and the Bourne in the south. We may infer from the scarp-foot position of the latter and its angular articulation with the upper course, that the lower Bourne of to-day is a subsequent stream which early diverted the head of a south-flowing stream which may have crossed the scarp at Porton Down, but whose further course is quite lost.

The process of stripping the *quadratus* Chalk from its *Micraster* foundation was, however, not confined to Wiltshire. After the Eocene beds had been largely removed from all but the deeper synclines of Central Hampshire, the attack upon the Chalk ridges began; this was, and is, maintained by a minor valley system that retained its flowing streams far longer than that of Salisbury Plain. Consequently the higher zones have been almost completely removed from the anticlinal tracts, although occasional relics still persist and give rise to abruptly scarped hills like Danebury near Stockbridge. The main *quadratus* scarp has now retreated westwards, as a result of the persistent undermining by the right-bank tributaries of the Test, almost to the county boundary.

Hampshire and Wiltshire have thus come to be separated in this region by a bold but broken upland ridge, the last considerable remnant of the highest portion of the Chalk. Its scarped edges look eastward and westward over regions whose contrasted histories are strikingly revealed in the contrasts of the present landscape (p. 155).

e. *Streams and Structures in the Wessex Coastal Belt*

To the south of the main drainage axis of Wessex – the Frome-Solent River – are the remnants of a series of northward-flowing streams which once formed its right-bank tributaries (Fig. 20). These remnants are to-day to be found in the Isles of Wight and Purbeck, but a little farther west, in the immediate hinterland of the Isle of Portland we may discern the vestiges of a still more southerly system of drainage, flowing not toward but away from the Frome-Solent River, southwards to the English Channel. No part of the south of England shows a more pronounced structural grain than the belt crossed by these tiny streams. Yet from first to last these little brooks ignore this impressive structural graining and flow in simple transverse courses, with greater or less discordance across or against the powerful tectonic gradients. Of course, it is quite normal for obsequent streams to flow against the dip, and for the outlets of scarp-rimmed anticlinal vales to push their headstreams backwards beyond the anticlinal axis on whose flanks they were first engendered. Osborne White has sought to explain the features of the Isle of Wight drainage on the basis of these considerations. We feel, however, that some individual discordances cannot be explained in this way, and that the discordance of a whole series of streams raises the question from one of merely local status to one of regional significance. Moreover, this group of streams has other unexpected features. Twin water-gaps occur at three or four places; there are a large number of recently abandoned wind-gaps; and the degree of integration of the subsequent drainage is surprisingly low for a series of strike vales whose structure is so eminently favourable to such development. These facts all imply that the drainage is still in a youthful and poorly adjusted condition and thus of relatively recent origin. This combination of arguments, indicating recent initiation coupled with systematic discordance, leads us to suppose that, like the rivers of northern Wessex, these southern streams are of epigenetic character and still in their first cycle of development. They are, in fact, another group of streams which began life by the emergence and uplift of the Pliocene sea-floor.

The Isle of Wight

The streams of the Isle of Wight may serve to illustrate both phases of the argument (Fig. 20). They flow generally from south to north across the central Chalk ridge, and while only two, the Medina and the eastern Yar, carry any appreciable drainage to-day, the ridge is more or less deeply notched at several other points. Both the functioning gaps are accompanied by partially abandoned water-gaps (at Carisbrooke and Yaverland) from which they are separated only by a mere knoll or mound of Chalk. Near the western end of the island, Freshwater Gate is also a true water-gap, though the sea has invaded it; and on the ridge between, there are some six wind-gaps (Fig. 20), while yet another lies still farther west. In all we may envisage a dozen independent streams flowing across the ridge in a space of 20 miles, of which four occur in two pairs. It is unlikely that such paired gaps can, in general, survive long, though we may grant that they will survive longest where the Chalk outcrop is narrowest – i.e. in its hog-back sections. Nor is it probable that even if these eleven streams were simply lateral consequents on the northern dip-slope of the Brixton and Sandown anticlines, as Osborne White[34] supposed, that they would have survived from the period of the Mid-Tertiary folding through the whole ensuing erosion cycle and enough of the current cycle to have notched the present sky line.

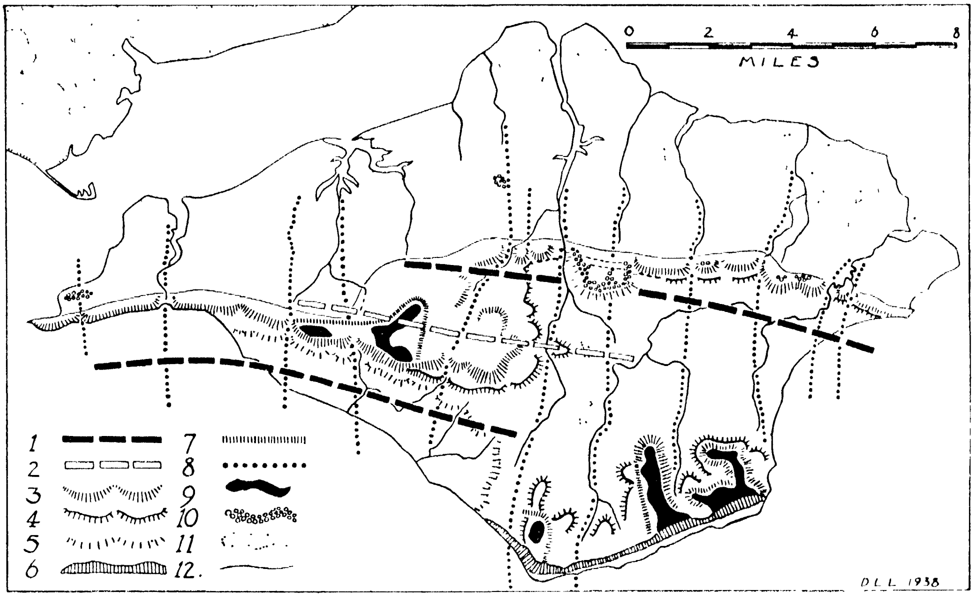


FIG. 20 – Structure and Morphology of the Isle of Wight. 1. Anticlines. 2. Synclines. 3. Escarpment of the Chalk. 4. Escarpment of the Upper Greensand. 5. Escarpment of the Ferruginous Sands. 6. Landslips of the south coast. 7. Pliocene shoreline feature. 8. Pliocene consequent streams. 9. Remnants of the Mio-Pliocene peneplain. 10. High-level gravels (above 250 feet). 11. Terrace gravels (50 to 150 feet). 12. Northern limit of the Chalk outcrop.

In point of fact, there is ground for questioning White's view that these streams are merely minor consequents, which arose on the northern flank of the folds and extended their territory southwards by the unroofing of the anticlines. Close examination reveals that some of them rise, or formerly rose, beyond the limits of

the scarp-rimmed vales which should contain their sources. The clearest case is that of the Medina (Fig. 20). It rises west of St. Catherine's Down within the lowland opened up along the Brixton anticline. This it leaves by a broad gap between the Central and Southern Downs which it was doubtless instrumental in bringing to its present form. It then cuts directly across the eastward-projecting salient of the resistant Malmstone outcrop preserved in the Calbourne syncline, thus isolating the outlier of this rock at Rookley. Thence it crosses the western end of the Sandown uplift, about Blackwater, to pierce the Chalk at Shide. In short, in half a dozen miles it crosses all the principal tectonic elements of the island while pursuing a course departing little from a straight line. Its neighbours on either side behave similarly. The Carisbrooke valley, which formerly headed beyond the wind-gap at Shorwell in the Brixton anticlinal vale, also crosses the Calbourne syncline without deflection. At Rowborough Farm it is crossing *Micraster* Chalk, but at Bowcombe, a mile or so further north on the end of the Sandown axis, it has cut down almost to the Upper Greensand, only to traverse the whole thickness of the Chalk again at Carisbrooke itself. A similar course may be inferred for the Niton branch of the eastern Yar. It heads in a large gap in the Southern Downs which has not the aspect of an obsequent combe such as might be expected to have arisen from the enlargement of the Sandown anticlinal vale; it resembles rather a true double wind-gap truncated seawards by the south-coast landslips. Moreover, its former continuation in the northern half of the island may perhaps be seen in the present Palmer's Brook, suggesting that before capture by the subsequent limb of the Yar this stream pursued a course right across the island quite independent of the underlying structure.

It might appear that this detailed discussion of a series of somewhat insignificant streams is of little profit, but considerable point is at once given to the argument by the fact that in the Isle of Wight we have the only direct evidence yet found in Wessex of the former presence of a late Tertiary sea. We have used the presence of double water-gaps and the frequency of wind-gaps to demonstrate the lateness and incompleteness of the development of subsequent streams adjusted to structure and so to infer that the drainage is still in the first cycle of its development. We have pointed to the demonstrable discordances of some of the streams which indicate that they have been superimposed from a surface planed across the structures. Elsewhere we have had to rely on morphological evidence to show that this planation should be attributable to the Pliocene sea: here stratigraphical evidence is also available. On the summits of Brading and Mersley Downs, in the eastern part of the central ridge, are patches of gravel at altitudes rather over 400 feet, which have long been known for their large imperfectly rounded beach cobbles of flint and Selbornian chert.[34] The deposits themselves are not marine, but clearly contain materials derived from the break-up of some older marine shingle. Osborne White argues that the parent deposit cannot be older than Pliocene since it contains pebbles of Selbornian rocks which must have been derived from nearby outcrops but were not exposed in the neighbourhood until erosion had bitten deeply into the Miocene folds. On the other hand, the weathered aspect of the pebbles and the altitude of the gravel in which they occur show them to be considerably older than any of the local drifts which can be dated as Pleistocene. From the non-occurrence of such beach pebbles farther west, White is inclined to suppose that the sea was restricted to the north-eastern part of the island, but if our interpretation is correct, the evidence of the drainage suggests that it covered a much wider

area. Within the island we think it covered all but the highest parts of the Central and Southern Downs.

Morphological evidence of marine planation is not well preserved, but we regard the marine plain as being substantially represented by the surface of the high ground between the Medina and the Carisbrooke valley, and by the spurs above Niton and Whitwell, while the aspect of the hog-back ridges of the Central Downs is wholly consistent with the view that they have been somewhat reduced from a formerly uniform level at about 550–570 feet. Above the vestiges of the marine plain at these altitudes, portions of the Central and Southern Downs rise fairly sharply to heights of 700 feet or over, and these quite clearly were not submerged. Not only is their altitude greater than that at which the Pliocene marine deposits consistently occur, but they are capped by an angular flint gravel which can only have accumulated under conditions of long-continued, undisturbed sub-aerial erosion. It represents the insoluble residue left after the destruction of over 1,000 feet of Chalk, for although it contains flints characteristic of the highest of the Chalk zones (*quadratus* and *mucronata*) it rests commonly upon the flintless Middle and Lower Chalk. We regard it as a remnant of the mantle of rock waste which developed on the surface of the Mio-Pliocene peneplain, modified perhaps by the washing out of some of the finer-grained constituents during the present cycle. These summits then, formed a group if islets in the Pliocene sea. Had the transgression lasted longer their destruction doubtless would have been certain and complete.

The Isle of Purbeck

In the area of the Isle of Purbeck the structural graining of the southern part of the 'island' is even more pronounced than in the Isle of Wight, and drainage integration is accordingly more advanced. Even so the 12-mile hog-back ridge of Chalk is notched four times by flowing streams and three times (at Tyneham, Lutton and Cocknowle) by wind-gaps marking the former southward extensions of the little streams which now flow towards the River Frome. Two of the water-gaps form the well-known double gap at Corfe, the western stream occupying a fine incised meander within the Chalk outcrop. The other two are occupied by short southward-flowing streams which may be regarded as obsequents specially favoured by situation. It is possible that these two obsequents grew out from longitudinal streams flowing on the Lower Cretaceous rocks, the one eastwards into Swanage Bay and the other westwards into the sea at a point near Lulworth Cove, and that they occupy gaps which had been cut down to levels of 300 and 200 feet respectively by consequent streams flowing to the north. This is probably true of the eastern gap at Ulwell, but it may be that the two gaps are not identical in origin. H. Bury[35] has recently examined the matter in detail and concludes that the stream which now flows southward through the Chalk at Arish Mell has always done so and was paralleled in its further course through the ridge of Purbeck limestone by another brook close by. This last is now represented only by a deep gap in that ridge at Pondfield. To explain these anti-dip courses, which he is satisfied cannot be regarded as obsequent, Bury invokes the same hypothesis that we here adopt – namely, epigenesis from an emerged Pliocene sea-floor. He is uncertain as to the extent of the transgression, but in the light of the morphological evidence from a wider region we feel that the accordance of the highest summits in the 'island' (631 feet on Portland Stone, 626 feet, 655 feet and 655 feet

on Chalk, and 637 feet on Oligocene limestone) marks approximately the level of the uplifted marine plain which may be presumed to have been cut across the whole area.

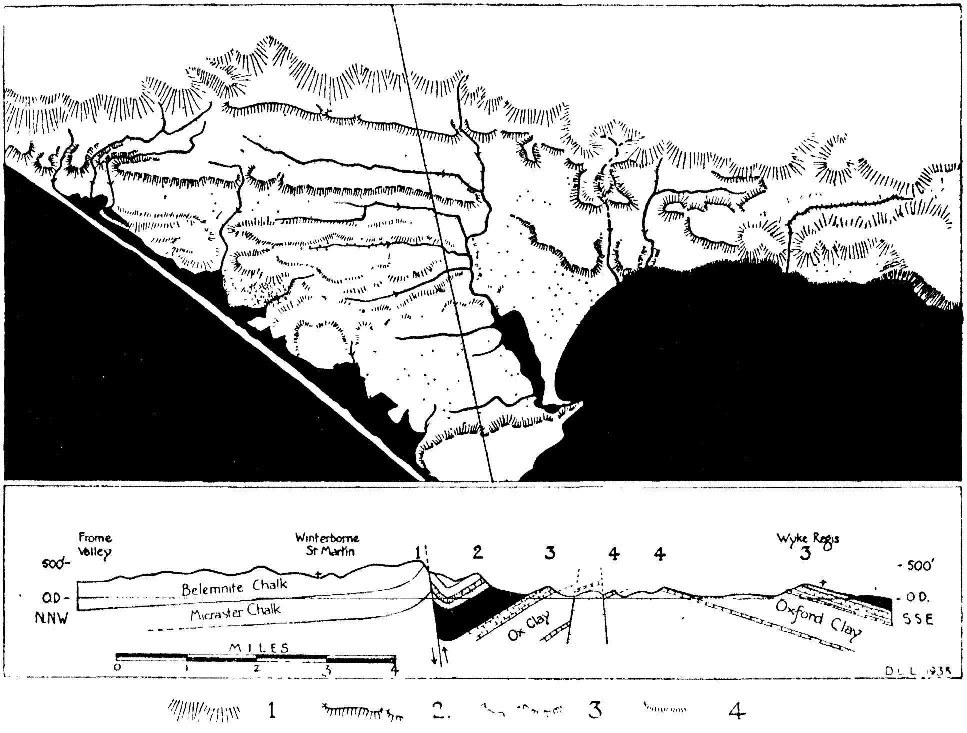


FIG. 21 – Streams and Structures in the Weymouth District. 1. Escarpment of the Chalk. 2. Escarpment of the Portland Stone. 3. Escarpment of the Corallian Limestone. 4. Escarpment of the Great Oolite. Clay Lowlands, stippled. Water, black. The section indicates the nature of the geological structure along the line drawn on the map and its continuation to the north-west.

Bury's view, that the stream now flowing through the Chalk gap at Arish Mell is a diminutive betrunked consequent superimposed upon the structures at the beginning of the present cycle, accords well with what is seen in the coastal region from this point westwards to Chesil Beach (Fig. 21). All along this coast a series of short streams which rise in the Chalk ridge of Blackdown and Poxwell, run southwards across the much disturbed belt of Lower Cretaceous and Jurassic rocks to the sea. They are best developed in the little triangular lowland of Jurassic rocks behind Weymouth which is crossed from east to west by the Broadwey anticline. Here the longest stream is the Wey which at first flows against the dip of the northern limb of this fold for some four miles, crossing in succession the ridges built by the Portlandian at Upwey, by the Corallian at Broadwey, and by the Cornbrash and Forest Marble at Nottington. Thus it reaches the Fuller's Earth clays exposed along the anticlinal axis, but only to cut its way out again through the enclosing ridge at Radipole and thus across the Oxford Clay to the sea. The river Jordan, in a course of only two or three miles, cuts its way out of the anticlinal Vale of Sutton Poyntz and then across the Coral-

lian ridge, but its neighbour, half a mile to the west, has the most noteworthy course in the district. It starts in a large combe in the Chalk east of Bincombe Hill, and then after skirting the very edge of the Vale of Sutton Poyntz it severs a tabular hill of Portland and Purbeck rocks by a mere cleft, and descends to the sea by cutting through the Corallian ridge against the dip, like its neighbour. No stream could get into a predicament so completely out of harmony with structure save by superimposition from an unconformable cover. It is at present on the verge of dismemberment but that is not to be wondered at; the wonder is that it has survived even so long.

West of the Wey the lowland displays a well developed series of strike ridges and small subsequent valleys which have evidently been opened up from the Wey itself in quite recent times. These strike streams appear to have dismembered a southward-flowing analogue to the Wey which is now represented only by the gaps in the Portland Stone at Friar Waddon, and the beheaded remnant which cuts through the Cornbrash at Fleet. Two miles to the west a nameless brook still cuts across the grain, with water-gaps at Rodden and Langton Herring, while at Abbotsbury three south-flowing brooks cut closely spaced but separate water-gaps through the Corallian ridge and traces of a fourth are seen at St. Catherine's Chapel. There are in all seven functioning water-gaps along the 10 miles of the Corallian ridge and all discharge southward against the dip.

The relations of these streamlets of the Dorset coastal tract to the structures they traverse have an importance altogether disproportionate to their diminutive dimensions, and it is on this account that we have here accorded them so extended a discussion. We believe that they cannot possibly be explained in any other terms than those of superimposition, and it is satisfactory to observe how they carry the testimony of epigenesis westward across southern Wessex to precisely that point where the evidence of the upland morphology led us to suggest that the Pliocene shore-line passed southward from the Dorset Downs into the region of the English Channel. Since we advanced this view in 1938, B. W. Sparks[36] has suggested that the sea did not finally withdraw from the Weymouth area until long after the Pliocene transgressive episode. He has cogently argued that the conspicuous planation of most of the strike ridges of the lowland at a single level could not have been effected by the minute streams of the area and must be attributed to wave work during a period of still-stand when the strand-line was 240 feet above its present level. He believes that the Wey and the other small streams which parallel it were initiated when the sea withdrew from this strand-line and that the strike streams of the clay vales have grown up since then. With this view we are inclined to concur.

Sparks has also postulated wave-cut platforms on the coastal fringes of the area at lower levels which do not concern us, as well as platforms on its inland margins at higher levels up to 480 feet. The evidence for such higher marine platforms is distinctly scanty in the area, and since it leads Sparks to reconstructions of the geography involving 'straits' across the main Chalk ridge about which we feel much dubiety, we prefer to believe that after the regression from the Pliocene shore-line the region was reduced by normal sub-aerial erosion till the waves of the 240-foot sea planed the area immediately north-west of Weymouth. Thus the gaps in the Portlandian ridge between Portesham and Upwey and the anomalous features associated with the Vale of Sutton Poyntz seem best regarded, as we have interpreted them here, as features inherited direct from the Pliocene sea-floor.

CHAPTER VII

THE DRAINAGE OF THE WEALD

From our discussion of the Wessex rivers we may turn to a renewed consideration of the problems of the Wealden drainage furnished with a new point of view and a new mode of attack. We have seen that in the pattern of the drainage system and its relation to the longitudinal Mid-Tertiary folds we have a valuable means of discriminating between areas in which drainage evolution has been continuous through two cycles of erosion and those in which it was interrupted at the close of the first cycle by the brief Pliocene marine trespass. In the latter areas the drainage system is characterized by a pattern whose major lineaments are of the utmost simplicity, and whose elements are predominantly transverse, displaying widespread and systematic discordances toward the longitudinal folds. Areas of uninterrupted sub-aerial erosion, on the other hand, show a dominantly longitudinal stream pattern, some of whose elements may, in rare cases, be longitudinal consequents never displaced from their original synclinal troughs, but will more usually be some form of subsequent or resequent growth. In these regions discordances are usually absent and when they occur are neither widespread nor systematically arranged; in general, the drainage is closely adjusted to the underlying folds.

a. *The Central Weald*

We may begin by examining the relations between streams and structures in the Central Weald, and for this purpose we may employ the quantitative structural map already described (Fig. 8) on which the deformation of a once level surface (the base of the Weald Clay) is shown by means of contours. When a tracing of the Central Wealden drainage is superimposed upon this structural map, many intimate relations between stream lines and rock folds stand clearly revealed. In general, the relationship is a sympathetic one. The major water partings are located, with but few exceptions, upon the major anticlinal crests, and even the exceptions are only such as prove the rule, for all admit of ready explanation. The major areas of structural depression, on the other hand, independently of the rocks of which they are composed, severally correspond with the headwater basins of each of the main streams, Medway, Teise, Rother and Ouse.

The main axis of the central area – the anticline of Ashdown Forest – forms the main water parting between the Thames drainage represented by the Mole, Medway and Teise, and the English Channel drainage represented by the Arun, Ouse and Rother. In the Ashdown Forest itself, the Ouse and the Medway are in conflict, and here the Medway, by opening up deep ghylls in the Ashdown Sands has captured some small headstreams from the Ouse, effecting a minor displacement of the watershed southwards from the anticlinal crest. When in the future the relief of this fold becomes inverted, the interior vale will certainly be opened up and drained by the Medway. Farther west there has been some displacement in

the opposite sense. In Worth Forest the Ouse has been successful, at the expense of the Mole, in enlarging its territory by feeders working back along the Grinstead Clay. Eastwards from Ashdown Forest where the main axis is prolonged by way of Wadhurst, the correspondence between fold and watershed is exact. The Teise on the one hand and the Rother on the other are here in equilibrium. Thus, throughout the whole of its length of some 30 miles the Ashdown Forest anticline forms a major water parting, and the same is equally true of the second major fold, that of Heathfield and Brightling, and of the related axis of Battle and Fairlight.

Equally striking is the manner in which all the principal down-warped areas serve as collecting grounds for the major rivers. The Medway waters, including some fault-guided subsequent outgrowths, are concentrated in the Groombridge basin before being passed on by a connecting trough to the smaller basin structure to the north-west of Tunbridge Wells. The Teise headstreams are gathered in the depressed area of Lamberhurst, and the Ouse and Rother share between them the main central syncline, the water parting near Hadlow Down corresponding exactly with the structural col which divides the eastern and western portions of the trough.

The headwater region of the Central Weald is thus characterized by a thoroughly sympathetic relation between streams and structures, the greater part of the drainage being evidently either of subsequent or resequent type. Discordances between folds and drainage lines are not, however, entirely absent, especially from the peripheral portions of the High Weald. Even so they are far from numerous and they lack that systematic arrangement on the map which might lead us to regard them as indications of an epigenetic drainage. The most notable case is undoubtedly the direct crossing of the strong Penshurst fold by the upper Medway. The incised meanders of the present course and the absence of any alternative outlet below the 400-foot level show clearly that the route taken is one of fairly long standing. This makes it easier to understand for it may well have originated at a time when the relatively resistant Lower Greensand occupied the synclinal tracts, and the Weald Clay was exposed along the core of the Penshurst fold. Under such conditions, the abandonment of a synclinal course toward the east for a northward course by way of the anticlinal clay vale would be a quite expectable change, recalling in miniature the changes envisaged by W. M. Davis in his classic study of the rivers and valleys of Pennsylvania. Whether or not this anticlinal crossing arose in this way, the local circumstances make it quite clear that no systematic or regional significance attaches to it. The Medway crosses the fold from south to north, but its principal tributary, the Eden, after flowing eastwards along the Weald Clay outcrop, turns abruptly southward across the fold to join the Medway at Penshurst itself, rather to the south of the anticlinal axis. Both streams show entrenched meanders inherited from some now vanished plain, and the suggestion naturally arises that the features we now see in this part of the Medway valley originated by the casual wanderings of the streams concerned on a wide valley-plain developed in the Weald Clay when that thick formation cloaked the anticlinal and synclinal areas alike.

Twelve miles to the east, the Teise similarly crosses an anticlinal axis which brings up the Ashdown Sand in the floor of its valley near Goudhurst, but here again a normal explanation is at least possible. At an early stage the upper Teise may well have flowed eastward to join the Rother along a syncline floored by

Lower Greensand. In such case the lower Teise must eventually have opened up a scarp-rimmed vale exposing the Weald Clay in the adjacent anticline, a condition affording it an excellent chance of capturing the upper Teise and its tributaries.

It will be noticed that the argument here put forward is the very one that was long ago used by Osborne White to explain the crossing of the Winchester fold by the Hampshire streams, but in our discussion, on pages 64–65, held to be inadequate. Lest this be thought inconsistent it may be well to point out that the cases differ in two vital particulars. In the first place it must be emphasised that the Hampshire discordances comprise a related group, while the Teise crossing is an isolated instance to which a hypothesis of capture, always a matter of special circumstances, is more likely to be applicable. And, secondly, any explanation of the Hampshire discordances by means of river capture would involve the displacement of streams from stable positions in synclinal outcrops of soft Eocene beds by capturing streams which had worked their way through an anticlinal barrier of resistant Chalk. The circumstances envisaged in the case of the Teise are precisely opposite and involve the displacement of a synclinal stream perched on a shrinking hard-rock outcrop by an outgrowth from a clay vale being opened at a lower level along the neighbouring upfold.

When we turn to the eastern portion of the High Weald we have no such evident discrepancies to record. The drainage is predominantly longitudinal, following the general trend of both the folds and the faults. Yet while the lower Rother, Tillingham and Brede and their lateral branches exhibit no evident discordances, there is a general imperfection of accord that deserves attention. The Tillingham and Rother are, generally speaking, synclinal streams, and the Brede, flowing in a valley cut throughout in Ashdown Sands but bordered on both sides by outliers of Wadhurst Clay, would seem to follow the axis of an upfold. But all three wander somewhat and the Rother most notably so. At Etchingham this stream departs from the main Central Wealden syncline to follow a minor anticlinal line near Salehurst, only to return a little later to the synclinal fold previously abandoned. We cannot believe that any systematic significance attaches to behaviour of this kind which suggests rather a loss of adjustment resulting from the chance wanderings of streams upon their own flood-plains. It is to be remembered that at no very distant date this region formed a part of the clay plain of the Kentish Low Weald; inspection of the contoured structural map reveals that a land surface very little above 400 feet could here be wholly developed in the Weald Clay. We may therefore suggest that the discrepancies between the observed and the expectable behaviour of these streams are to be attributed to their former wanderings upon a base-levelled clay lowland of insignificant relief.

One portion of the High Weald remains, however, and here the discordances between streams and structures may possibly be of greater significance. The southern margin of the High Weald is a region of small streams and rather ill-defined small-scale structures. While no spectacular discordances are found, the streams show a considerable degree of independence of structural control. The clearest evidence of discordance is found in the western part of the Ouse drainage, where three small streams pass from the Slaugham syncline across the line of the Cuckfield axis, marked by inliers of Wadhurst Clay in their valley floors. Further west two wind-gaps in the anticlinal ridge suggest two more transections of the fold making five within a few miles. Other cases in the Cuckmere and Ashbourne drainage in East Sussex might individually be dismissed as accidental,

but collectively are probably significant. Moreover, not only does the drainage of this zone show a measure of disregard for structure, but it also displays many of the features of immaturity. Even where there is no visible discordance, the large number of independent sub-parallel headwater streams of the Ouse is strongly suggestive of a drainage system so young that thinning out and integration have hardly begun. We feel justified therefore in suggesting that, unlike the rest of the High Weald where drainage evolution has been continuous since the Mid-Tertiary folding, this southern fringe resembles rather the Wessex and London Basin areas which suffered a Pliocene submergence.

b. *The Pliocene Transgression in Sussex*

It is a significant fact that one cannot draw a meridional line across the South Downs and the belt of country at their foot anywhere between Beachy Head and the confines of Hampshire, without crossing a considerable fold-axis. This fact serves at once to reveal the measure of the contrast with the structural simplicity of the North Downs and the evident kinship between the southern Chalk range and the Wessex region. Further, it follows that the Sussex streams, which all flow generally from north to south, must all transect one or more fold-axes during their relatively short courses. This evidently applies to the Arun which crosses the Greenhurst anticline; to the Adur which crosses the Pyecombe fold; to the Ouse which makes a spectacular crossing of the anticline of Kingston and Beddingham, and to the Cuckmere which crosses the same fold-line near the village of Arlington.

The same relationship is shown in several less obvious cases in which the streams concerned have ceased to flow and part or all of the valley is now dry. In the western part of the Downs, the deep wind-gap at Cocking marks the former course of a stream whose shrunken representative is seen in the diminutive Chichester Lavant. This valley cuts directly across the syncline of Chilgrove and the complementary anticline of the Dean valley before reaching the Chichester lowland. Any suggestion that this abnormal behaviour might be explained by supposing that the stream has had a composite origin or has suffered some drastic change in the past, seems to be negatived by the fact that the dry valley next to the west, which descends from Chilgrove Manor, behaves in exactly the same way. Again, in the neighbourhood of Brighton an analogous case occurs. Gathering its 'headwaters' just below the crest-line a little east of Ditchling Beacon is a dry valley which cuts southward to Brighton, and in its lower part carries the main road and railway from Lewes. For the first mile or two of its course it falls with the dip into the Falmer syncline, but it then proceeds to behave quite discordantly and trenches its way across the anticlinal axis east of Hollingbury Castle against dips of 10° or more. The Patcham valley which lies immediately to the west behaves in similar fashion (though much less obviously). It crosses the same synclinal line at Withdean and completes its course against north-westerly dips, although the actual synclinal line has practically died out here.

This flagrant disregard, by both the major and minor streams, of the structures which underlie their catchment basins suggests strongly that, as in the case of the Wessex rivers, we are here dealing with a single-cycle epigenetic drainage. Alternative explanations might possibly account for the observed discordances in particular cases. Thus it is possible that the crossing of the Pyecombe fold by the Adur, or of the Beddingham fold by the Cuckmere, may have come about by some

process of fairly recent drainage adjustment effected in the soft Weald Clay, though it is not easy to envisage the manner of such changes. Indeed, a change of the reverse kind seems almost to have occurred in East Sussex, where the head of the Cuckmere has narrowly escaped being diverted to Pevensey Levels by a longitudinal outgrowth along the Weald Clay. Moreover, no such arguments are available in the cases of the Arun and Ouse whose courses across the fold-axes are deeply incised respectively into the Greensand and the Chalk, nor in those of the dry valleys of the Chalk dip-slope. An alternative hypothesis which regards these latter as of composite origin has recently been suggested by Sparks,[37] but it encounters serious difficulties, as a single example will show. If the dry valley of Stanmer Down, behind Brighton, has not always cut across the Hollingbury Castle fold, it must have drained at an earlier stage along the Falmer syncline, floored by Eocene rocks. It is evidently unlikely that a small stream draining the southern slope of the complementary anticline should effect a clean breach through 200–300 feet of Chalk and divert the synclinal stream beyond. In his attempt to make such an event seem plausible Sparks has to resort to what can only be described as special pleading. It is of the essence of our argument that special pleading will not suffice since we are dealing with a regional phenomenon.

We may therefore regard the rivers of Sussex and Wessex as members of a single series occupying the whole belt of country westwards from Beachy Head to Salisbury Plain. Their discordances show them to possess a common origin. Their uniformly southward direction of flow indicates that they arose on a single gently-tilted constructional slope. It is natural to enquire as to the extension of this slope northwards into the Wealden region. Relics of Pliocene deposits have been found only at one point on this surface, namely, at its eastern end above Beachy Head, and though we may hope that similar deposits will come to light farther west, it is evident that such finds would do nothing to delimit for us the precise area which was submerged. Indeed, the evidence of the rivers is probably our best guide on this point, but it may be usefully supplemented by a consideration of the upland relief.

Throughout its extent in the London Basin, and as far as the evidence goes in Wessex also, the upper or shoreward margin of the Pliocene marine plain is rarely much below, and practically never above 650 feet, and in no case is it known to rise to 700 feet. So generally is this the case that we may reasonably assume that the same is likely to be true for Sussex also, and we may look for evidence of a break of slope at this level, coupled with planation at slightly lower altitudes. Dissection of the South Downs has been so thorough-going that the evidences are actually of the scantiest but, such as they are, they confirm our expectations.

In the western part of the South Downs the evidence is perhaps clearest. The whole crest-line from Westburton Hill (just beyond the Arun gap) to Wether Down by the headwaters of the Hampshire Meon, is over 700 feet in altitude, and rises in Butser Hill to 889 feet. It can hardly be doubted that this high ground was continuous with the elevated areas of the Hampshire Downs above Selborne, and the Greensand uplands of the western Weald. The whole of this area must have escaped submergence. In this tract the Wealden rivers are normally adjusted to structure and offer a contrast with the discordant relations of the dip-slope lavants. The latter occupy the region south of the 700-foot contour where traces of a bench may be seen in the uniformity of summit level of a number of hills at distances of two to four miles from the scarp crest. On the *cor-anguinum* Chalk of the Dean

valley anticline we find summits of 593, 569, 600, 677 and 671 feet, and further west on the *quadratus* Chalk 558, 550, 534, 530 and 600 feet. All may be regarded as having formerly risen to a level of 600–670 feet, but some have since been degraded by the same erosive agencies that have isolated them from each other.

In each of the blocks of the Downs to the east, between Arun and Adur, and between Adur and Ouse, rather similar relations hold. A part of the crest-line rises above 700 feet, to 783 feet at Chanctonbury Ring and 813 feet at Ditchling Beacon; the spurs running southward flatten out in some cases at 600–660 feet, and isolated summits at rather lower altitudes lie beyond (549, 553 and 603 feet to the west of the Adur and 583, 645, 616 and 624 to the east of it: they are developed on zonal horizons ranging from high in the *quadratus* Chalk almost to the Chalk Rock). Here again are vestiges of the marine bench and of the unsubmerged ground behind. But in the neighbourhood of the Arun and Adur gaps and practically everywhere eastward of Plumpton, the scarp crest itself is at altitudes close to 650 feet. In other words, the present summits of the Downs were, in these stretches, part of the marine plain and the Pliocene sea clearly passed beyond the Chalk outcrop into the Weald. Whether it did so merely in a series of marine embayments or whether the submergence of the Sussex Weald was general, and the unsubmerged areas round Chanctonbury Ring, Ditchling and Firle Beacons, and Windover Hill simply formed low islands in the Pliocene sea, it is not easy to decide. But from the considerations already noted on p. 79, it is probable that the latter alternative is correct. These considerations would place the shore-line northward of the portions of the Ouse and Cuckmere Basins where lack of integration of the drainage and a measure of independence of structure are conspicuous. Such a location shows a strong correspondence with the 700-foot contour on the map of the base of the Weald Clay (Fig. 8). This would seem to imply that the Pliocene sea planed its way across the whole of the Weald Clay outcrop to the margin of the High Weald of that time, a far from improbable relationship.

On this view the area in which the drainage is of single cycle type covers practically all Sussex. The boundary line, the Pliocene shore-line, may be drawn tentatively so as to skirt the southern margin of the High Weald and to run thence to Petworth and Bignor and so along the South Downs just below their crest into Hampshire. South of this line a new drainage appeared, but the streams were not entirely free to take direct southward courses as in Wessex. The presence of small tracts a few miles in extent which were never completely base-levelled and still stood up slightly above the marine plain must have introduced a complicating factor. Some of the new streams possessed direct courses right across the emerged plain and of these the Arun, Adur, Ouse and Cuckmere have survived until to-day and become the master streams of the region. In the intervening areas streams would take their rise in the unsubmerged islands and flow in shorter courses to the sea and it is possible that the streams responsible for the Jevington and Washington wind-gaps were important members of this group. Herein lies a possible explanation of the otherwise not very comprehensible fact that although these wind-gaps are cut down to levels as low as 290 and 320 feet, no trace either of the diverted headwaters or of the diverting streams themselves can be discovered in the drainage pattern of the Low Weald. Moreover, we may now see why no single subsequent stream came to dominate this lowland in the way that the Eden and Beult tributaries of the Medway have appropriated the whole of the northern Weald Clay outcrop for some 40 miles from eastern Surrey almost to the confines of Romney Marsh.

In Sussex each of the transverse streams found the Weald Clay exposed in its course at the very outset of the cycle and each trunk developed its own branches.

c. *The Rivers of the Sussex Low Weald*

Bury, in 1910,[20] in his thoughtful and penetrating analysis of the drainage of the western Weald, considered that the Adur was the first to enlarge its territory in the clay lowland, being favoured by the fact that its course lay across the planed-off Greenhurst anticline. But he also gave evidence for believing that at a later stage the Arun was much more successful and enlarged its territory northward across the main Wealden axis and the probable original divide between the northern and southern streams, by capturing two headwater branches of the River Wey. This hypothesis has recently been reviewed by Kirkaldy and Bull.[38] who concurred with Bury's findings except on a minor matter of the likely interval between the capture of the two streams concerned. But there is reason to think that a very important part of the evidence has been overlooked and that earlier views have been wrong in a quite important respect.

The western of the two captured branches of the Wey was termed by Bury the Dunsfold stream. It collected the obsequent brooks from some 10 miles of the Lower Greensand scarp, from Haslemere to Hascombe, and carried them eastward by Dunsfold village. To-day it here turns southward – the elbow of capture – to join the Arun. Before capture it flowed a mile or so further east before turning northwards through the wide breach in the Greensand scarp which ultimately narrows to a true gap at Bramley three or four miles south of Guildford. At its northward bend the Dunsfold stream was met by a similar but smaller stream which gathered the obsequent brooks of the section of the Greensand scarp east of the gap as far as Ewhurst. This little stream still forms the headwaters of the Bramley Wey, a misfit wandering in an ample and gently graded valley of very mature aspect. The continuations of this mature valley floor are found west of Dunsfold where, as Bury pointed out, the headwaters of the Dunsfold stream have cut their courses some three or four score feet lower. There can evidently be no question about this capture. All the text-book criteria – the beheaded misfit in the too ample valley, the elbow of capture, the incision of the diverting stream below the elbow and the presence of dissected remnants of the old valley floor above it – all are clearly present. We may confidently say therefore that before the capture occurred the Arun-Wey watershed ran eastward for some 10 miles from Haslemere to the village of Rudgwick (the line is still the county boundary between Surrey and Sussex). Quite possibly at a still earlier phase the Lower Greensand was preserved along part of this line by the eastward continuation of the Haslemere syncline, and the Dunsfold stream originated by opening up a scarp-rimmed vale on the Weald Clay along the axis of the Hindhead anticline. If so we can well understand why capture by the Arun headwaters did not – indeed, could not – occur earlier than it did.

The second stream which Bury supposed to have been captured by the Arun from the Wey is that which he called the Horsham River. Its principal head-stream rises on the southern slopes of Leith Hill and flows south as the North river to Slinfold about four miles west of Horsham. Here it is joined by a stream, which Bury called the Warnham Brook, which rises in the Weald Clay of Surrey and flows southward for half a dozen miles to beyond Horsham. At Christ's Hospital Station it makes an abrupt bend through more than a right angle and in two or three miles more joins the North river at Slinfold. The combined stream

flows westwards, but after two miles or so bends south and is joined by the Dunsfold stream to become the main south-flowing trunk of the Arun. Bury supposed it formerly to have curved northwards around the village of Alfold to become the original head of the Bramley Wey.

Such an interpretation presents difficulties. Bury supposed the east-to-west section from Horsham to Alfold to have originated as a strike stream at the foot of the Greensand scarp when the latter occupied a much more southerly position than it does now, and the North river to be an obsequent tributary which became extended northwards as the scarp retreated. At best the mechanism of this process would be doubtful, but doubt is much increased by the fact that the Warnham Brook rises not on Leith Hill but in the open Weald Clay lowland, while, to the west of the North river, the streams draining the Greensand scarp around Ewhurst turn, as we have already noted, directly into the head of the Bramley Wey. The North river, considered as an extended obsequent outgrowth of the Horsham stream, would thus be the only example of its kind. Two other points, moreover, must be taken into account. First, there is Bury's point that the North river has evidently been rejuvenated, and with its lateral tributaries is incised some score or so feet below an older mature topography. But that older topography is at a level too low by a good deal to be regarded as an upstream extension of the mature valley floor of the Bramley Wey. Second, there is the striking bend at Christ's Hospital, and immediately south of it a broad gap at 175–180 feet through which the railways from Horsham pass to Arundel and Shoreham. Beyond lies the present head of the Adur and it is difficult to avoid the conclusion that the North river and Warnham Brook formerly joined at Christ's Hospital at the bend which still preserves their angle of confluence, and passed through the gap to the south as the former headstreams of the Adur.

This reconstruction need occasion no surprise, despite its implication that the Adur, rather than its more powerful neighbours the Arun and the Ouse, should have been the first south-coast stream to push its headwaters back across the main Wealden axis to the northern Greensand escarpment. For recourse, once more, to our contour map of the base of the Weald Clay (Fig. 8) will show that on the Mio-Pliocene peneplain in the meridian of the Arun gap the Weald Clay stretched uninterruptedly above what is now Horsham and St. Leonard's Forest, while to the east the Ouse had already uncovered the sandstones of the High Weald, and in the west the Arun had to deal with the cherty Lower Greensand. As the level of the country became progressively lowered by denudation these relations altered. The Greensand scarp retreated southward and, becoming rather insignificant, ceased to impede the Arun: the Horsham Stone appeared low in the Weald Clay and held up the Adur. Two headstreams of the Arun extended far enough to tap the Dunsfold stream on the north-west and the North river at Slinfold. The first effected a direct transfer of territory from the Thames to the Channel drainage: the second merely a change of outlet towards the Channel. But thus aggrandized the Arun is in an improved position to continue to enlarge its territory. In the north-west its watershed with the Wey shows by its marked asymmetry that it is by no means stabilised and is bound to retreat northward. First it will rob the Bramley Wey of its Ewhurst headstreams, and later it will progressively diminish the extent of the territory held by the Wey south of the Greensand gap. In the north-east, Kirkaldy and Bull[38] have pointed out a similar instability of the Arun-Mole divide and have noted that the Arun has recently effected small gains at the expense of the Mole

at the foot of Leith Hill and on the northern margin of St. Leonard's Forest. And although these authors are unwilling to concede the suggestion, which we put forward in a map published in 1938,[39] that what are now the more easterly head-streams of the Horsham River, draining the southern slopes of St. Leonard's Forest, formerly passed through a gap some three miles south-east of Horsham into the branch of the Adur that heads at Nuthurst, we feel that in the larger context of the present argument our earlier suggestion gains considerably in strength. By this capture the Arun has completely outflanked the Adur, and, by developing a common watershed with the Ouse, deprived the Adur of any future contact with the Central Weald.

Of the Ouse itself relatively little need be said. Its relations with the Medway and Rother headwaters are, as noted on p. 76, features of long standing essentially inherited from the Mid-Tertiary cycle. In the west, however, it appears to have encroached successfully in the present cycle on territory that might have fallen to the Adur. In the Sussex Low Weald the divide between Adur and Ouse is close to the main London-Brighton railway (it is more accurately marked by the road from Ditchling to Haywards Heath); but a little further north the Ouse has successfully appropriated the whole drainage of the Slaugham syncline and the Ouse-Adur watershed runs from east to west for several miles along the Cuckfield ridge. No structural reason can be adduced to explain this success. Both Ouse and Adur doubtless shared the drainage of the Weald Clay of this area on the Pliocene plain, but presumably when denudation had gone far enough to isolate the Weald Clay in the syncline, the Ouse had developed the lowest available outlet and this fact determined the fate of the whole synclinal tract.

One other point about the Ouse requires mention. Kirkaldy and Bull,[38] in order to account for the isolation of the detached Chalk upland between the Ouse at Lewes and its left-bank tributary called Glynde Reach, felt it necessary to seek for headwaters of the latter stream in the High Weald. These they believe to be represented 'by the Buxted-Uckfield branch of the Ouse, which has been captured near Worth Farm, one mile east of Isfield, by the more active Slaugham-Lindfield-Fletching stream'. Nothing in the local circumstances near Isfield suggests that such a capture has occurred, but more importantly, nothing of the kind is required to explain the isolation of Mount Caburn. This, we are confident, has been accomplished simply as a incidental result of the opening up of the Vale of the Brooks along the anticline of Kingston and Beddingham. That this can be effected by through-going streams as they cross an anticlinal axis is well known, and is well exemplified by the Chilcomb Vale developed by the Itchen at Winchester, or by the Vale of Warnford where the Meon crosses the same axis a dozen miles to the east. The latter vale is closed at its eastern end by a narrow ridge of Chalk that spans the fold-axis and separates the Warnford Vale from the adjoining Whitewool Vale. This, in its turn, is partically closed on the east by a ridge of Chalk which was evidently once intact but is now ruptured leaving only buttress ridges at each end. Beyond this again there is the Vale of East Meon, of similar character but widely open to the Weald at its eastern end. We believe that in its development the anticlinal enlargement of the Ouse valley south of Lewes has gone through all these phases. At one stage a ridge of Middle and Upper Chalk doubtless connected Mount Caburn across the fold to Beddingham Hill and closed the vale on the east. Later this ridge was ruptured. To-day even the abutments of such a broken ridge have gone and only the basement of Lower Chalk on which

it stood survives to separate the Upper Greensand outcrop in the Brooks from the main outcrop to the east. Because the structural horizons all stand higher here in relation to base-level than is the case in Hampshire, the stream which breached the eastern wall of the vale was able to extend headward into the Weald where it prospered exceedingly on the soft rock outcrops.

The success of Glynde Reach in the Low Weald is, in fact, so surprising as to deserve some attention. This little stream has managed to collect the drainage of nearly all the Low Weald (but none of the High Weald) between the Ouse and the Cuckmere, except a very narrow zone fringing each of the main streams. Moreover, it has opened out an area below the 50-foot contour amounting to some 8 or 9 square miles which contrasts strongly with the narrowness of the zone at a corresponding altitude along the Ouse and Cuckmere. This contrast, moreover, is repeated in even more striking degree when the Cuckmere is compared with Pevensey Levels. No direct evidence has come to our attention which would suggest an explanation of this curious relation in which minor streams appear to have been more effective agents of denudation than major ones. We can only offer the suggestion that at some earlier period both the trunk streams were bordered by spreads of gravel at levels 100 feet or more above the present flood-plains. When a negative movement of base-level occurred each trunk stream would incise itself leaving the gravel spreads to protect the soft rocks on which they rested, what time the unprotected Weald Clay and Gault outcrops away from the Ouse and Cuckmere were being effectively lowered by the little brooks draining to Glynde Reach and Hurst Haven (the stream of Pevensey Levels). If it be asked where are the gravels which this hypothesis postulates, it might perhaps be fairly retorted, where are the gravels contemporary with those in which the notorious Piltdown skull was found? Little ground still survives in this part of the Low Weald at the level – possibly corresponding to the Boyn Hill stage of the Thames – at which we envisage the gravel spreads being laid down. The gravels appear to have survived long enough to have impressed a peculiarity upon the landscape which is otherwise inexplicable, but not long enough to prove that they were ever there!

Whatever the reason for the phenomenon we have described, the fact remains that the Cuckmere has been so much less effective in enlarging its valley than have its two small neighbours that it has, apparently, only just managed to survive. In fact, had the Hurst Haven not been deprived of its downcutting power by having its valley almost wholly submerged by the sea in late Pleistocene times and subsequently filled with alluvium, the Cuckmere would surely have been already diverted.

All this, however, contrasts very strongly with the state of affairs in West Sussex beyond the Arun, where the drainage pattern is dominated by the presence of the only important subsequent stream in the whole region – the western Rother. Doubtless the contrast is in part associated with the changing lithology of the Lower Greensand and the resulting development of the important cuesta of the Hythe Beds. This ridge divides the Weald Clay outcrop from the longitudinal scarpfoot vale below the Downs and it is along the latter the Rother has found an opportunity for facile expansion.

While the importance of these considerations is evident, it is probable that the uniqueness of the Rother among Sussex streams derives partly from the fact that it alone has survived from an earlier cycle in which subsequent development was already well advanced. It is, of course, possible that some integration has

gone on during the current cycle, and that at the beginning of this cycle the upper Rother turned southwards at Midhurst to drain through the Cocking gap. That there was an upper Rother, wherever it discharged, is very strongly suggested by the manner in which it has encroached headwards around the western end of the pitching anticline of Fernhurst, and has thrown out obsequent feeders like the Oakshott, Empshott and Bradshott streams. A few miles north of Petersfield these obsequents have cut notable breaches in the cuesta of the resistant Malmstone, and have successfully tapped the spring waters issuing from the Chalk beyond. This success bespeaks an early start upon a piratical career which is still by no means terminated.

d. *Stream Development on the South Downs Dip-Slope*

Returning now from the Sussex Weald to the South Downs we may here consider the view recently put forward by B. W. Sparks[37] that the dissection of the South Downs has been accompanied by the outgrowth of strike streams which were in many cases later dismembered. Sparks accepts the general view of the origin of the drainage advanced in the previous pages and has brought forward evidence that its later development took place while base-level fell intermittently and a series of strand-lines ranging from 475 feet down to 180 feet above modern sea-level were cut in the dip-slope (p. 143). Where the dip-slope is simple, as between Brighton and the Adur gap, the streams of the Pliocene platform became successively extended as the sea withdrew southward: elsewhere Sparks envisages a more complex development. In the areas where the Downs are complicated by the Dean valley and Kingston upfolds the sea, even at the highest level, was restricted to the southernmost flanks of the Downs, and Sparks concludes that north of his 475-foot strand-line adjustment of drainage to structure was already going on. He points out that the upland of Newmarket Hill between Brighton and the Ouse at no point descends below 500 feet, so that no stream could have crossed it to reach the 475-foot sea. With this view we may concur. While Eocene beds survived in the Falmer syncline, outgrowths of the Ouse on the east and the Stanmer valley behind Brighton on the west doubtless exploited their opportunity till they partitioned the synclinal depression between them unequally at Falmer.* What is, however, not warranted is Sparks's belief that the syncline from Falmer westward emptied, not southwards to Brighton, but over the 433-foot col north of Hollingbury Castle Hill into the 430-foot sea near Patcham. The continuity of this ridge from Hollingbury Castle to Ditchling Beacon strongly suggests that it has never been anything but a watershed and that Eocene rocks have had little part in its composition. And the difficulties of dismembering this synclinal stream if it were formed have already been commented upon (p. 80).

In a similar way Sparks argues that north of Chichester the Chilgrove syncline and the Dean valley anticline both carried structure-guided streams at his 475-foot stage. For a variety of reasons, depending on details of interpretation which cannot be treated here, this view does not command our assent. But what is more important to our discussion is that Sparks goes on to suggest that the two streams united and passed westwards across the line of the Chilgrove dry valley mentioned earlier

* We may note in passing that the synclinal Kingston Winterbourne had, before the falling water-table curtailed its activities, begun the inversion of the relief of the anticlinal swell that lies on its southern side. In this it is paralleled by the behaviour of the Wiltshire Ebble (see p. 68 and Fig. 10) which though definitely synclinal has effectively opened up the anticlinal Vale of Bower Chalke.

(p. 79) and over a col at 475 feet into the valley of the River Ems almost on the Hampshire boundary. We find this suggestion both unnecessary and very difficult to credit: unnecessary, because it is at least equally open to us to interpret the 475-foot col at the northern end of Bow Hill as due to the intersection of a dry valley head with a section of the *quadratus* escarpment, as to regard it as a stream-cut gap: and incredible, because such a stream system once formed should have been as proof against capture as is the present upper Lavant in the Dean valley against dismemberment by the dry valleys of Goodwood Park working back through the ridge of Goodwood racecourse.

It is to be noted also that Sparks's belief in the early development of structurally guided streams in the Chalk has led him to revive a view of the nature of the *quadratus* escarpment first adumbrated by Topley in 1875.[18] Topley regarded the group of hills between the Arun and the Adur of which Cissbury is the highest member, as 'the remains of an escarpment'. Sparks has suggested that at the time of his 475-foot strand-line two scarp-foot streams approximately followed the *Marsupites* zone west and east from the interior of the upland near Blackpatch Hill to the two river gaps, and that, by the time of his 380-foot stage, short streams draining directly to the coast had 'cut back through the secondary escarpment to disrupt the subsequent streams beyond'. We prefer the interpretation given by Osborne White, in 1924[11] which regards the discontinuity of the *quadratus* escarpment as 'a sign of immaturity rather than decadence'. Discontinuous escarpments are well known elsewhere, as will be readily recalled by anyone who knows the bold 'nabs' made by the Corallian limestones along the borders of the Yorkshire Moors north of Pickering and Helmsley. They arise, in fact, wherever a scarp-forming outcrop is crossed by closely spaced streams, as we believe to have been the case in this part of the South Downs since Pliocene times. That the *quadratus* Chalk can give rise to a continuous scarp feature when the relations to streams and outcrops are more favourable is clearly shown by its strong development along the Hampshire-Wiltshire county boundary described on page 70.

One further conclusion reached by Sparks deserves mention here – namely, the suggestion that at his 180-foot stage the Ouse flowed from Newhaven by Seaford and the broad 'gap' at Chyngton Farm into the Cuckmere. The evidence adduced seems to us insufficient to support this hypothesis. Rather do we see here the expectable consequences of the 'cleaning out' of the last remnants of the Eocene infilling of the Seaford syncline. The watershed west of Newhaven which Sparks finds anomalous is not part of the system of Chalk divides but is sited almost entirely on Eocene beds; the flat at 177–190 feet north of Chyngton Farm to which he attaches much importance might well have been cut – if it is a river-cut flat – by the Cuckmere when sufficient Eocene material remained in the syncline to prevent that river diverging westwards to Seaford; and the Chyngton 'gap' is revealed by careful examination of the contours to be part of the exhumed sub-Eocene surface beautifully moulded across the synclinal axis.

e. *The Central North Downs and the Northern Weald*

Of all the Chalk uplands which lie south of the line of the Kennet and Thames the North Downs are beyond doubt the simplest in structure and build. Uncomplicated by minor folds, they form a true cuesta which exhibits its most typical characters in the middle parts of its long course of about 95 miles. A regional dip of about 1° results in an impressively steep escarpment and a singularly uniform

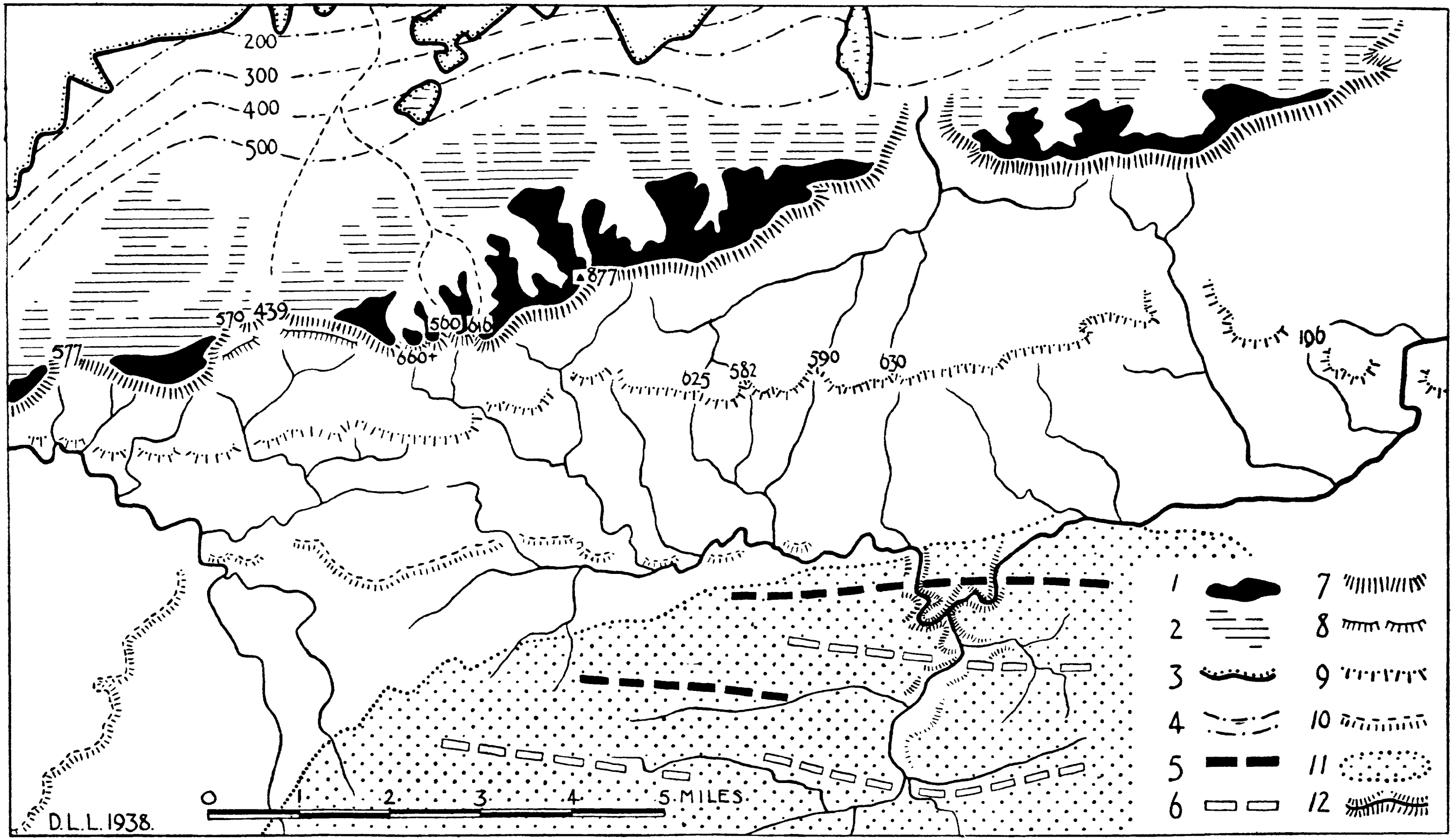


FIG. 22 – Drainage and Morphology between the Mole and the Medway. 1. Remnants of the Mio-Pliocene peneplain. 2. Remnants of the Pliocene marine platform. 3. Boundary of the Eocene outcrop. 4. Generalized contours of the sub-Eocene surface. 5. Anticlinal axes. 6. Synclinal axes. 7. Escarpment of the Chalk. 8. Escarpment of the Malmstone. 9. Escarpment of the Lower Greensand. 10. Escarpment of the Lower Paludina Limestone. 11. Outcrop of the Hastings Sands. 12. Incised meandering courses of the Eden and Medway near Penshurst. Altitudes of wind-gaps and of sub-Eocene contours in feet.

dip-slope 7 or 8 miles in width. To the east the dip becomes even less, and in East Kent, beyond the Stour, the outcrop broadens to almost 20 miles and the cuesta becomes a plateau. In the other direction, passing westwards through Surrey, a rapidly increasing dip leads to drastic narrowing of the outcrop till, in the Hog's Back itself, the latter is reduced to a mere causeway connecting the North Downs proper with the Chalk uplands of Hampshire.

At the present day the five trunk rivers of the northern Weald flow across this cuesta in direct transverse courses. Probably the original consequent streams of Mid-Tertiary times flowed in an essentially similar fashion directly down the dip, and at first sight it seems reasonable to regard the rivers flowing through the present water-gaps as the successful members of that early consequent family. But this simple view is not in accord with the known history of the region, for both at the eastern and western ends the Pliocene sea advanced across the North Downs and into the Weald. In these areas the drainage must be in its first cycle of development, as Bury clearly showed for the western area some forty years ago. Between Netley Heath in Surrey and Wrotham Hill in Kent, however, the North Downs remained inviolate, and in this tract drainage evolution has gone on uninterruptedly from Mid-Tertiary times.

Between the Mole and the Medway, a distance of 36 miles, no stream makes a successful traverse from the Central Wealden uplands to the Tertiary lowlands of the London Basin (Fig. 22). The transverse elements of the drainage are far from dominant, and the master streams of the region are the Eden, a subsequent outgrowth of the Medway, and the longitudinal sections of the Mole and Medway themselves, all of which follow the outcrop of the Weald Clay. What were presumably once the trunk streams – the Wandle and the Darent – have long since been beheaded, and it is doubtful if any trace of their Wealden headquarters can now be discerned. On general grounds we might argue that the upper Mole, which descends from Worth Forest roughly along the line of the Brighton road, was, like the latter, aiming for the Merstham gap, and is, in fact, the diverted head of the Wandle. Similarly we may connect the upper Medway, flowing a little east of north to Penshurst, with the Darent which continues this line. Certain difficulties, however, confront this suggestion.

In our discussion of the Central Wealden drainage we saw reason to suppose that the courses of the rivers in that region had never been directly transverse, but were from the first composed largely of longitudinal elements following the trend of the folds. It is probable that the original upper Medway always found an outlet towards the east, and was debarred from following a direct course by the uplifted ridge following the Penshurst anticline. In this case the Darent would doubtless have headed independently on the northern side of the latter fold.

Whether this be so or not, any connection between the lower Darent and the Central Weald has long since been severed and throughout the present cycle its headwaters have been practically confined to the Vale of Holmesdale. It has long been assumed that the gravels of the Darent valley contained no debris from the inner Weald, but F. Gossling[40] has demonstrated that pebbles derived from the sandstones of the Weald Clay series are abundantly present. This being so we may regard the three faint notches in the Lower Greensand cuesta immediately to the south of the Darent headstreams as representing the avenues by which this material entered the lower valley. The altitudes of these wind-gaps, if such they are, are so high, and the development of the obsequent combes that have grown up in

two of them is so advanced (Fig. 22), that we must believe that they were abandoned at the very outset of the present cycle.

What appears to be true of the Darent in relation to the Lower Greensand escarpment may also be claimed for the Wandle and the escarpment of the Chalk. In both cases any headwater territory that may have survived south of the scarp crest at the end of the Mid-Tertiary cycle of erosion, was fairly rapidly extinguished when uplift initiated the present cycle and gave new impetus to the activities of the subsequent Eden and Mole. It is true that some have found reason to doubt whether the Wandle ever had any Wealden headwaters at all, and believe that the small quantities of Lower Greensand debris found in the gravels of the Wandle valley have travelled to their present resting place by some indirect route, independent of the conspicuous gap in the escarpment at Merstham.[41] The latter, moreover, has been regarded as being not a true wind-gap but a mere recession-col formed by the intersection of the receding scarp face with one of the dip-slope valley heads.[42] Such recession-cols are certainly well developed in the Caterham district nearby, and a uniform recession of the whole scarp by half a mile would produce a very large additional crop of similar notches. They would, however, all resemble the Caterham gaps in being at a relatively high level, 100 feet or more above the level of the Merstham col (440 feet). We therefore prefer to regard the latter feature, so much broader and lower than the other actual and potential notches, as a true wind-gap, through which the last surviving Wealden headstreams of the Wandle continued to flow during the earlier phases of the present cycle.

A further point regarding the drainage of this part of Surrey deserves our attention. Not only have the Weald Clay subsequent streams grown to the extent of dominating the drainage, but they have in their turn formed the starting point for the outgrowth of a series of considerable obsequent branches which now form the distinctive feature of this portion of the Wealden drainage. These obsequent valleys presumably began as deep combes on the face of the Lower Greensand escarpment, in similar fashion to those which may be seen to-day south-east of Westerham (Fig. 22). In course of time they breached the cuesta and captured the drainage of the Vale of Holmesdale beyond. Bury[20] regarded these streams as favouring his contention of a marine planation of the whole Weald and as being incompatible with the idea of continuous denudation through two sub-aerial cycles. He envisaged the Chalk and Greensand escarpments arising and retreating successively down the dip from the central area of uplift to their present position. Concurrently, subsequent streams would appear and migrate in the same sense, and it seemed to Bury self-evident that the streams which arose at the foot of the later-formed Greensand scarp could not be expected to outstrip and capture those which were earlier in the field. He therefore argued that both sets of streams must have begun *de novo* on a marine plain at the beginning of the present cycle. But we feel that the very existence of the well-developed obsequent drainage necessitates the belief that the subsequent streams have been in existence for a much longer period than Bury's hypothesis implies.

The present cycle could hardly have sufficed for the growth of subsequents and obsequents as well, and we are therefore inclined to reverse Bury's argument and claim the obsequent drainage as evidence of two continuous cycles of sub-aerial erosion. Bury's objection to this view, moreover, is not really valid. At the end of the first cycle both sets of longitudinal streams were doubtless well established on the peneplain and both would be equally close to base-level. During

the present cycle the circumstances would all favour the Weald Clay streams and enable them to compete with and finally extinguish their Lower Greensand rivals. As a point of objective evidence in favour of this view we may draw attention to the description of a high valley floor in this region by F. Gossling.[43] This old valley floor is dissected by the modern valley of the Oxted Brook and was clearly eroded by that stream in an earlier epoch. The Oxted Brook is evidently no recent outgrowth of the Eden but is already of quite creditable antiquity. This can only be the case if we suppose that the whole of the Mid-Tertiary erosion cycle was available for the earlier phases of that adjustment to structure of which the outgrowth of the obsequent brooks is merely the latest development.

We may summarize the foregoing discussion as follows. It may confidently be assumed that both the Darent and the Wandle originally possessed Wealden headwaters, those of the latter stream being possibly represented to-day by the upper Mole, while those of the former rose on the northern flank of the Penshurst anticline. At the close of the first cycle both had been decapitated by subsequents, the one on the Weald Clay and the other in the Vale of Holmesdale. During the present cycle the unequal struggle has been continued and the Wandle entirely excluded from the Weald by the development of obsequents draining to the longitudinal Weald Clay lowland, and the same process is at present diminishing the area of the Darent catchment. As a result of this development the valley systems of the Chalk dip-slope and of the Low Weald have already come into opposition along most of this belt. With the steady diminution in the size of the tract drained by the Darent in the Vale of Holmesdale, the function of the crest of the Greensand cuesta as a longitudinal water-parting declines in importance. We may envisage a day, possibly before the present cycle has run its course, when this process will be completed. The Darent gap will become a wind-gap like that at Merstham; the two watersheds that to-day follow the two main scarps will be replaced by one only. The integration of this part of the Wealden drainage will then be accomplished.

From these conclusions an interesting corollary arises. Since no large trunk streams have crossed the line of the Chalk escarpment in this region at any time during the present cycle, there has naturally been no opportunity for that development of deep valley re-entrants in the escarpment alternating with bold, herringbone salients, which is so characteristic of the Central Chilterns. In this respect the North Downs show characters recalling those of the West Chiltern scarp beyond the Princes Risborough gap and for much the same reason. Only in the neighbourhood of the Darent gap, and again near Merstham where C. C. Fagg[44] was led to suggest 'that the slopes of the escarpment represent the northern sides of old Chalk valleys' is there even a tendency towards the development of those features of form so characteristic of the Central Chilterns and the Berkshire Downs.

d. *The Evolution of the River Wey*

Both because of its many features of high intrinsic interest, and of the considerable volume of discussion which these features have provoked, the River Wey appears to deserve rather more extended treatment than the other rivers of either Wessex or the Weald. Its most spectacular feature was naturally the first to attract attention, and as long ago as 1895 W. M. Davis, while visiting this country, observed that 'the Wey has recently taken off the head of the Blackwater'.[19] He referred, of course, to the diversion of what were formerly the headstreams of the Blackwater at the very point where they seem about to escape from the Weald

through the broad gap in the Hog's Back just east of Farnham. This capture later received incidental mention from various writers (e.g. Mackinder in 1902[30]) but it was not until 1908 that the whole sequence of events by which it was brought about was thoroughly established by Bury.[45] At the same time, however, Bury drew attention to another problem which may be stated thus. In diverting the Blackwater the Wey became possessed of a tributary (the Farnham River) which drains some 50 square miles of the Wessex Chalk around the town of Alton in eastern Hampshire. The question thus arises how this tract of Chalk ever came to drain into a Wealden stream at all. This matter was discussed by Osborne White in 1909.[14]

In 1910 Bury[20] undertook a comprehensive examination of the drainage of the whole western Weald and from it derived conclusions of the first importance. Incidental reference has already been made to some of these points, but it will be convenient to recapitulate here some of Bury's principal arguments. His essential conclusion was that the drainage of the western Weald could best be understood by regarding it as having originated upon a plane of marine denudation now represented approximately by the Wealden summits. In support of this view he urged two arguments which he believed to be applicable throughout the whole region. The first was the non-coincidence of longitudinal streams with longitudinal folds implying that the former had arisen independently of the latter and at some subsequent period. The second was the high degree of success in the enlargement of territory of those streams whose original courses over the marine plane would have been favoured by the outcropping of soft strata along the crests of planed-off anticlines. For the Wey drainage area he developed a third argument depending upon the demonstrably late date at which the existing subsequent streams of that drainage made their appearance, and the surprising lack of integration displayed by the rivers of the region during the early part of the present cycle.

All these arguments are as valid to-day as when Bury first urged them, and all of them point definitely to the conclusion that the streams of the areas concerned originated upon a marine plane cut indifferently across the Mid-Tertiary folds and that they are still in their first cycle of development. Our only qualification concerns the precise extent of the region to which this conclusion may fairly be applied. For the areas with which Bury was mainly concerned and from which his arguments were chiefly drawn, his conclusion has been entirely corroborated. The stratigraphical and morphological evidence of the Pliocene transgression over the western North Downs has already been adduced (pp. 50–51) and is, of course, completely independent of the testimony of the rivers. For the headwater regions near the central axis, on the other hand, Bury's conclusions were based largely upon inference from the neighbouring areas, and we do not think they are actually supported by the observed features of the rivers in this central tract. These resemble rather the rivers of the High Weald in their well-adjusted relations to structure and presumably have had the same history extending through two cycles of erosion.

Apart from this modification, Bury's views as to the origin of the Wey drainage system may be unreservedly accepted, and since he has also demonstrated the broad lines by which this drainage developed to its present condition it will be enough if we do no more here than summarize his findings. This may best be done by the aid of the accompanying series of diagrams. (Fig. 23). The first of these shows the outline of the modern drainage for reference, and superimposed

upon it the probable courses of some of the initial streams at the beginning of the cycle, and the probable extent of some of the principal Cretaceous formations as they cropped out upon the Pliocene marine plain which bordered it on the south. It follows closely the similar reconstructions made by Bury but differs somewhat in regard to the presumed outcrop geology. The chief cause of this divergence lies in our adoption of a value for the thickness of the Gault much in excess of the thickness measured in the outcrops below the Hog's Back. The Gault has undoubtedly been subjected to mechanical attenuation here and the recorded thicknesses are misleading.

The disposition of the outcrops shown on this map goes far to account for the phenomenal success achieved by the Wey in capturing the neighbouring streams during the brief course of the present incomplete erosion cycle. Indication is given, following Bury, of the probable courses of three of the early consequent streams for which evidence exists both in the form of transported fragments of Hythe Chert and in the morphology. Doubtless there were originally other such streams, but all have succumbed to the encroachments of the Wey, and if we discount the diminutive Seale stream which is, often enough, dry, we may say that no water from this catchment crosses the Chalk outcrop except by the gap at Guildford. The fact appears to be that of all the Surrey streams the Wey was favoured by the shortest course over the resistant rocks of the region. All the streams to the west had to traverse a varying breadth of Malmstone or Chalk preserved in the Tilford syncline; those farther east encountered an ever broadening outcrop of Chalk. Moreover, the Mole was so far hindered in down-cutting by the resistant Hythe Cherts that it has been almost entirely ousted from the Greensand dip-slope by the Tillingbourne which has grown out from the Wey; the place where its consequent head should be is now occupied by obsequent outgrowths from its own subsequent section on the Weald Clay.

While it is relatively simple to see how this disposition of the outcrops at the beginning of the cycle would favour certain streams at the expense of others, it is not possible to follow the stages by which the outcrops retreated under denudation to their present position. Doubtless all the streams as they crossed the Gault would develop strike feeders, but we may assume that those of the Wey early gained an advantage and decapitated the streams descending the Greensand dip-slope around Milford on the west and Peaslake on the east (Fig. 23B). In the course of time these subsequent streams would shift uniclinally northwards till they came to occupy stable positions along the synclines of Tilford and Blackheath. The stream occupying the latter was destined to be disrupted by the brook which later exposed the little scarp-rimmed clay vale along the Peasemarsh anticline; but the Tilford stream finding a soft bed in the Folkestone Sands developed from strength to strength. Before noting its further extensions, however, we must draw attention to the activities of the Blackwater. This stream was probably favoured by receiving a considerable drainage from that part of the western Weald which had remained unsubmerged in Pliocene times and so from the outset took rank as the master stream of the region. Where it crossed the western prolongation of the Peasemarsh fold the Gault was already exposed and here subsequent feeders grew up. That on the east severed both the Shoelands and Puttenham streams, but not before the latter had cut a recognizable notch in the Hog's Back at a level of 455 feet. That on the western side grew more slowly, for it could only extend by the slow pushing back of the scarp feature of the Malmstone, but in due course it tapped the

waters of the last of the consequent streams shown on our map. The course of this stream in this locality and the altitude of its valley floor immediately prior to its diversion are indicated by the wind-gap south of Crondall village, and by the presence of chert-bearing fluviatile gravels at heights of 400–420 feet on the Malmstone and Chalk and on the Reading beds beyond. From this time forward only the two main streams, Wey and Blackwater, continued to cross the Chalk and the run of the outcrops began to approximate to those which we now see. Competition was now between the Wey and the Blackwater, and in this contest the latter was destined to failure. First the strike stream occupying the Tilford syncline continued its headward extension and intercepted the consequent head of the Blackwater itself, at a time when the floor of that valley stood at about 300 feet. Another capture a little further west may be of much the same date. The most westerly of the consequents of this area, which had already been diverted at the point where it crossed the Chalk, now suffered a second rupture a little higher upstream. This time the diverting stream was a strike feeder of the Blackwater following the Gault outcrop, and the capture occurred just below the Malmstone scarp leaving a wind-gap at 338 feet. Although the altitude is a little greater than that of the Blackwater valley at the time of its invasion by the Tilford stream, it is quite possible that the immediate cause of this more westerly capture may have been the rejuvenation which followed the diversion of the Blackwater itself. As a result of these two events the strike stream of the Tilford syncline had now appropriated the whole drainage of the Hindhead region including all those streams which the Blackwater may have inherited from the previous cycle. As a result of this very considerable accession of territory the original Tilford stream continued the active degradation of its bed. Obsequent streams appeared on its northern side occupying the old consequent valley floors at Blacknest, Waverley, Puttenham Common and Lydling. Of these the Waverley stream operating on the line of the consequent Blackwater was naturally the most successful and ultimately succeeded in capturing the only considerable stream leaving the Weald west of Guildford. This last is the capture which has so often been described.

Finally, we may re-state the special problem of the Alton branch of the Wey drainage, without, however, being able to offer any final solution. This stream has a valley some 10 miles long which falls naturally into two apparently distinct halves whose junction point is at the town of Alton. The upper part is excavated wholly in Chalk and is now virtually dry, though it represents the drainage artery of the whole area of the Alton Chalk Plateau. It trends from south to north as far as Alton where the lower section of the valley takes up a direction about 60° E. of N. From Alton northwards, however, a dry valley continues the line of the upper or Tisted section of the main valley, and runs due south from a col at the Golden Pot Inn, cut 70 feet or so below the crest of the upland. Beyond the col the valley line is continued yet again by one of the headstreams of the Whitewater with but little variation in direction all the way to the Thames some 20 miles distant. The appearances strongly suggest that we have here the dismembered portions of a major consequent stream originally rising on the same watershed as the Meon but flowing away in the opposite direction to the longitudinal consequent Thames. Attractive as this view may be, there are considerable difficulties in the way of its acceptance.

The chief of these concern the origin of the lower portion of the stream between Alton and Farnham. If the Tisted portion is to be regarded as a diverted conse-

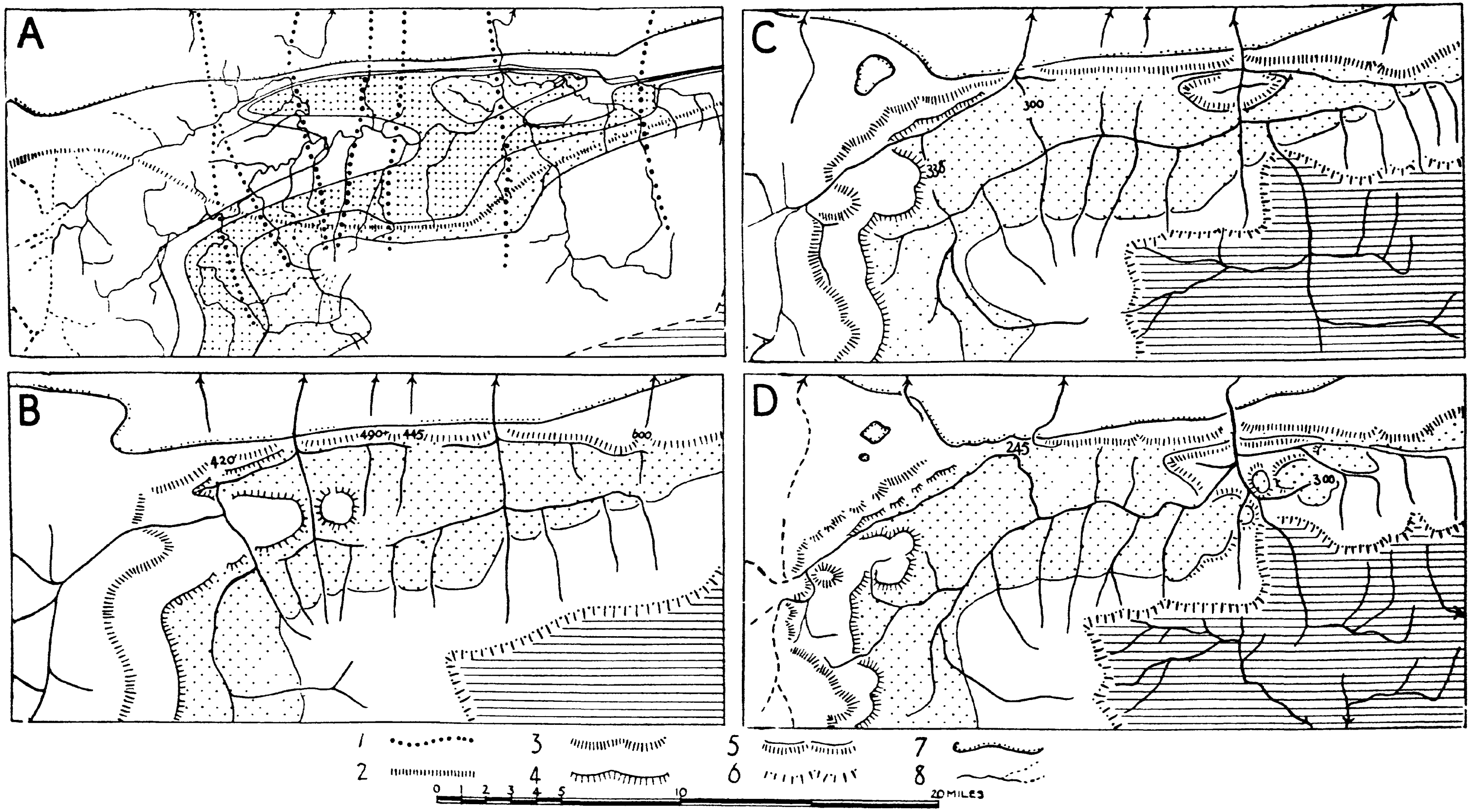


FIG. 23 – Evolution of the Wey Drainage. A. Inferred outcrops and drainage lines on the emerged Pliocene platform superimposed on existing drainage. B. Inferred outcrops and drainage lines after deepening of main valleys to *c.* 400 feet. C. Inferred outcrops and drainage lines after deepening of main valleys to *c.* 300 feet. D. Inferred outcrops and drainage lines at the time of the Farnham capture. 1. Inferred drainage lines on the Pliocene platform. 2. Inferred margin of the Pliocene land. 3. Escarpment of the Chalk. 4. Escarpment of the Malmstone. 5. Escarpment of the Bargate Beds. 6. Escarpment of the Hythe Beds. 7. Margin of the Eocene outcrop. 8. Existing streams and dry valleys.

Stippled areas – Gault, Folkestone Sands, etc. Ruled areas – Weald Clay.

quent, the Farnham section must be regarded as the divertor. Now the lower portion of this stream certainly is a subsequent outgrowth of the Blackwater and we have already noted that it captured the head of a northward flowing consequent just south of the Crondall gap when the latter had been lowered to a level of 420 feet or so. The col at the Golden Pot is, however, at a much higher level than this (actually 583 feet) and if it represents a diversion of the Tisted stream, it is clear that this event must have happened very early in the present cycle and cannot possibly be ascribed to the same subsequent stream that effected the capture at the lower level.

It is possible, of course, that the diverting stream was a subsequent tributary, not of the Blackwater, but of the Crondall consequent itself. Such a stream may well have grown up at a very early stage in the present cycle, following the outcrop of the marly Lower Chalk between the more resistant upper divisions of the Chalk on the one hand and the Malmstone on the other. The activity of the present Caker stream, which occupies just such a position at the foot of the Chalk scarp between Alton and Selborne, gives plausibility to this view, especially since this stream has quite recently succeeded in piercing the Chalk escarpment and diverting the whole of the drainage of the Tisted valley from Chawton upwards. But it is more difficult to see how our supposed subsequent could have bitten back rapidly through a good deal of the Chalk itself at so early a stage in the denudation of the district. Moreover, such a view implies that the stretch of the Wey between Alton and Farnham is itself composite, arguing that it was formed by the integration of two once independent strike streams, the one developed along the Chalk marl, the other along the Gault. Such integration could hardly be other than fairly recent, and the connecting link through the resistant Upper Greensand outcrop might reasonably be expected to show youthful characters. Actually it is one of the most puzzling features of this particular reach of the Wey that it flows in a broad open valley which everwhere possesses smoothly graded and mature slopes, across all the formations from the Middle Chalk to the Folkestone Sands, and shows very little constriction and certainly no immaturity at the point called Cuckoo's Corner where it traverses the Malmstone.

It was this maturity of aspect and indifference to the run of the outcrops which led Bury to suggest that this section of the Wey must have been inherited from 'a broad valley . . . already formed here in the Chalk (and perhaps Eocene beds) and already connected with the Blackwater near Farnham before the Wealden strata of this region were uncovered'.[45] This is tantamount to saying that it was inherited from the drainage of the previous cycle, and implies that this particular valley formed part of that extensive area in the western Weald, and the eastern part of the Hampshire Chalk which escaped submergence.

Unfortunately the evidence is still too fragmentary for us to trace the Pliocene shore-line here with all the precision that we could wish, but such evidence as is available points to the correctness of this view. The lowest portions of the Farnham River, which are certainly subsequent and have arisen during the present cycle, are known to be situated within the area of Pliocene submergence, for the most westerly outlier of Pliocene shingle lies on the crest of the Downs about two miles W.N.W. of the village of Bentley. From this point south-westwards, however, the ground rises, and throughout the whole area of the Tisted drainage the culminating points of the upland lie rather above the highest levels to which the Pliocene marine bench has been traced elsewhere. Long continued examination

of these summits, moreover, has never revealed to the writers any deposits resembling the high-level marine sands and shingles of other regions, but, on the other hand, relict masses of Eocene material are not infrequently observed. The conditions, indeed, resemble those of the highest parts of the North Downs, and it seems a fair inference that both regions have had similar histories. If this be so, the Tisted stream must be regarded not as a dismembered simple consequent stream, but as the complex product of two cycles of erosion whose early beginnings are quite lost to us. It is possible that Osborne White was right in believing that traces of an originally synclinal and longitudinal drainage are 'implied by the convergent tendency of the minor valleys, and by the decline in the altitude of the Wey-Itchen waterparting, in the areas of synclinal structure',[32] but at present we see no means whereby the argument could be pressed further.

CHAPTER VIII

THE EVOLUTION OF THE LOWER THAMES DRAINAGE SYSTEM

(i) INTRODUCTION

In Wessex and the Weald, regions traversed by well-marked Alpine folds, the relations of drainage to structure clearly demand an hypothesis of superimposition, one for which there is a considerable measure of independent support. In the London Basin the emphasis of the problems at issue is somewhat different. The transection of anticlinal zones by valleys is here less conspicuous and, in so far as it occurs, might be dismissed as of little significance, in view of the gentle and discontinuous character of the structures and the softness of the rocks. Both in general and in detail there is, indeed, considerable discordance between drainage and structure as is well illustrated by the course of the Thames itself. The Upper Thames after traversing Goring gap joins the Kennet northwards of the centre of the main synclinal trough, but the joint stream, instead of approaching closer to the synclinal line, at first forsakes it altogether turning northwards into the great incised loop cut in the Chalk past Henley, Marlow and Maidenhead. From the last-named place the river flows south-eastwards following closely the general dip-direction and then turns eastward. West of London it lies roughly in the centre of the synclinal trough, but it edges southwards until at Gravesend it is incised in Chalk beyond the main Eocene outcrop (p. 126). The course of the Lower Thames is thus highly anomalous and might appear to reflect very strongly the consequences of epigenesis. There is, in fact, no doubt that the drainage of the London Basin was superimposed from a Pliocene cover, for there is no escape from the conclusion that Pliocene deposits were widely spread in the area. The *direct* evidence of epigenesis is, indeed, stronger here than elsewhere in the region. It may appear anomalous therefore that the present course of the Thames and its chief left-bank tributaries cannot, in fact, be cited as evidence of superimposition; they reflect later diversions of drainage brought about by glacial agency.

At elevations lower than that of the sub-Pliocene surface there are several major series of superficial deposits in South-East England. They comprise the hill or plateau gravels, associated with loam and boulder-clay in some cases, and the valley or terrace gravels associated with brickearths, and at the lowest levels with muddy or peaty alluvia. This rough two-fold grouping is evidently based on situation or altitude; the valley gravels lie plainly within the present valleys, while the plateau gravels cover interfluves or cap isolated hills of circumdenudation. Since there is comparatively little lithological variation among the deposits, such a grouping is, in many cases, adequate for the purposes of the geographer, for in considering agriculture, water-supply and site values generally, the precise age of a gravel sheet is of small moment. Even so, the rough physiographic classification breaks down in places: the lower sheets of plateau gravel often appear as

upward continuations of the terrace sequence of the valleys and in other cases lie on the floor of broad valley-like depressions, not now tenanted by any through drainage. The measure of apparent continuity between the plateau and the terrace-gravel stages differs, indeed, very markedly from one part of the region to another and progress in the elucidation of the fashioning of the land surface depends upon the establishment of a chronology of denudation-stages which shall prove consistently applicable to the whole region.

The problems of drift-geology, as such, in our region are of great complexity. For our present purpose the cardinal fact is that the drifts mark stages in the excavation of the landscape, and a study of their physiographic relations affords one of the few means of direct attack upon the problem of the development of the river system.

The record of the drift deposits is much fuller in the London and Hampshire Basins than in the intervening tract of the Weald and the Wessex Chalk. In part this reflects the age-old relationship whereby material worn from the uplifted margins was dumped in the synclinal hollows. Other considerations arise, however. On the northern margin of the Hampshire Basin it may clearly be seen how the present valleys and their ancestors widen in passing on to the Eocene rocks, thus giving room for the origin and preservation of a full series of plateau- and terrace stages marking episodes in the growth of the valleys. We turn, therefore, to the great Mid-Tertiary synclines in search of a denudation chronology, which shall afford a key not only to the physiographic evolution of the synclinal tracts themselves but of the intervening upwarped area. The London Basin takes pride of place by virtue of the fact that here the deposits of several of the glacial stages can be studied in relation to the earlier and later periods of landscape shaping. Here, indeed, the glaciated meets the unglaciated country and we may hope to construct a chronology applicable to both. In its surface geology East Anglia constitutes a natural continuation of the north-eastern parts of the London Basin. As is well known, parts of the drift record are very fully inscribed here, though as yet imperfectly deciphered. It cannot serve as our type region for a denudation chronology for two good reasons. In the first place it can tell us little of the older (pre-glacial) stages of the drift record, for except locally on and near the coast the evidence is buried beneath the sheet of glacial drifts. Secondly, its tectonic relations are entirely different from those of the rest of our region.

In the London Basin the superficial deposits can be grouped in three broad chronological stages, viz.:

I. The higher hill and plateau deposits, exclusive of those belonging to or earlier than the marine Pliocene series.

II. The lower hill and plateau gravels associated north of London, with undoubted glacial deposits (boulder-clay) and probably including representatives of two distinct glaciations.

III. The terrace-deposits of the Thames and its tributaries, including, in the later part, evidence of phases of arctic climate, probably contemporary with the return of true glacial conditions elsewhere in Britain.

The succession of events represented by this brief summary is long and complex and we require to establish subdivisions in the three main stages. Broadly speaking there are three methods by which this may be attempted. In the Stage III or terrace-deposits the normal palaeontological methods avail, for the deposits

yield both fossils and human artifacts referable to dated series. In the higher deposits no such evidence is available and we should naturally turn first to lithological evidence as the basis of our groupings. This proves to have severe limitations, however. The Stage I deposits are simple in constitution containing material gathered within the synclinal basin (chiefly flint) together with debris from immediately beyond the Chalk escarpments (chiefly derived from the Lower Greensand). Stage II witnesses the advent of large quantities of Triassic debris, accompanied, in the main mass of glacial deposits, by a widely garnered and extremely various suite of erratics from northern and eastern Britain. In Stage III few if any new elements can be recognized; the deposits consist of the more durable constituents of the earlier stages mixed with much local debris. Though it is thus possible to separate the Stage I from later drifts on a basis of composition we cannot subdivide those of Stage II, or separate the latter in all cases from those of Stage III on a basis of composition alone. It is the third or physiographic method which affords the only basis of classification applicable consistently throughout all three stages. We can range the subdivisions no less than the main stages in order of elevation and relative age. This method is more delicate than that based on lithology, less so than that based on palaeontology, but for the greater part of the record it is the only one that can avail us. Its basis must be made entirely clear before we can proceed. Briefly, we accept it as a cardinal principle that spreads of fluvial or fluvio-glacial gravel mark the low ground of their periods and occur in 'gravel-trains' which fall in level downstream. This is equivalent to saying that the whole drift record is in reality a series of terrace-stages, complicated only by the presence in some areas of glacial ground-moraine. The basis of the method is the indisputable fact that the Pliocene shore-line features and marine abrasion platforms are essentially unwarped over the greater part of the region. This clearly implies that all later surfaces are unwarped. But the drift deposits themselves afford independent evidence of the correctness of our basic postulate. Even if the absence of warping were a pure assumption it would be subjected to a very stringent test in the application of any theory of regular gravel-trains or terraces. The slightest warping would derange or disjoint such terraces beyond recognition; it would be by coincidence only that any trace of regularity could survive. In fact, the degree of regularity revealed is so great as to demonstrate the absence of appreciable warping quite apart from the evidence of the attitude of the Pliocene shelf.

(ii) THE DENUDATION-CHRONOLOGY

In tracing the morphological development of the region during Pleistocene times we require to deal with two distinct but closely related matters – viz.: the changes of the region in general profile and its changes in plan; or, in other words, the progress of 'base-levelling' and that of drainage development. In these circumstances it seems best to begin by outlining in broad terms the chronological succession of drift-stages as they apply in a selected type area within our region. It is needless to say that the chronological succession could not be established by reference to any one such small area; it must of necessity apply to the whole region. From the standpoint of the geologist, a consideration of the morphological development is an important ancillary aid in constructing the succession. The geomorphologist, however, interested in the surface itself rather than the deposits that form it, may expect a repayment for his contribution in the form of a tested

chronology, which may serve him as basis, as in the analogous enquiries of the historical geographer, for a series of period-pictures.

The remarkable stretch of country in South Bucks, lying north of the Thames and between the tributary valleys of the Wye and the Chess-Colne is well fitted for the role of type area. Within an east-west belt only 12 miles wide all the successive stages of down-cutting, base-levelling and drift accumulation are conveniently displayed. In neighbouring regions the same succession is either condensed by the local omission of certain terms, or else the evidence is more widely scattered so that the succession of stages is a matter for inference, not for direct observation.

On the northern edge of the belt, Pliocene deposits cap the Eocene outlier at Coleshill, south of Amersham, at an elevation of 550 feet. This fixes our upper datum, and the succeeding drift stages come on in order southwards at decreasing elevations as follows:

Stage I. Near Chalfont St. Giles, at elevations of 400–450 feet, there are surviving masses of the simply constituted Pebble Gravel, the earliest fluviatile deposit which can be associated with the Lower Thames drainage system. The Pebble Gravel is seen to better advantage farther east, but these masses serve to fix its local relative position, 100 feet below the Pliocene deposits and 50–100 feet above the greater part of the Stage II drifts.

Stage II. These deposits cover a very wide area and though lithologically similar throughout are susceptible of a real and significant morphological division.

At Chorley Wood Common and over a wide tract extending north-westwards to Amersham Common and eastwards into Hertfordshire, there are expanses of stony clay. The coarser debris of the deposit is predominantly local in origin, but on the southern margins of the sheet far-travelled Triassic elements are also present. We concur with Barrow in regarding this deposit as a boulder-clay, the product of ice moving south-eastwards from the Chiltern plateau;† it is referred to below as the 'Chiltern Drift' (11a). It ranges from about 370–500 feet and thus overlaps, as it were, the Pebble Gravel in elevation. At several localities east of Chalfont St. Giles and elsewhere in the area, masses of Pebble Gravel are involved in this glacial drift.

South of the tract in which the Pebble Gravel and the Chiltern Drift occur, there is a marked descent in the level of the general surface to about 350 feet. This descent takes place along a well-defined line running from near Loudwater past Chalfont St. Giles and thence to the north to Rickmansworth. Southwards lies the extensive gravel plateau around Beaconsfield, Gerrards Cross and Burnham Beeches. The gravels rest for the most part on Eocene deposits and are grouped together on the maps of H.M. Geological Survey, but morphologically several 'gravel trains' or terrace stages can be traced across the plateau.

The higher parts of the gravel sheet around Beaconsfield and Horn Hill (370–340 feet) form part of what we have termed the *Higher Gravel Train* (11b). They are separated from the broader *Lower Gravel Train* (11c) by a distinct break of slope well seen south of Beaconsfield and near Chalfont St. Giles. The Lower Gravel Train falls in level eastwards from 320–290 feet. Beyond its southern edge at Littleworth Common, Hollybush Corner, etc., is a further sharp descent of the

† Two views are possible as to the provenance of this ice, that it was local ice formed on the Chiltern plateau, or the margin of an ice mass of more distant origin overrunning the Chiltern scarp from the north-west.

surface to about 250 feet, at which level there is developed a narrow but well-marked terrace, which has been termed the Winter Hill Terrace (IId) from its clear development at Winter Hill, west of the Thames at Bourne End. It is possible to show that the deposits of this terrace are broadly contemporary with those of the second or main glaciation of the country to the east. More recently F. K. Hare has mapped a further terrace at about 200 feet O.D. which he names the Black Park Terrace (from Black Park, near Iver).

Stage III. South of the Winter Hill Terrace the lower terraces of the Thames are developed in descending order southwards as follows:

IIIa. Boyn Hill Terrace (*c.* 175 feet)
IIIb. Lynch Hill Terrace (*c.* 130 feet).
IIIc. Taplow Terrace (*c.* 100 feet).
IIId. Flood Plain Terrace (*c.* 65–70 feet).

The Lynch Hill Terrace was first distinguished by Hare in 1947. The others, as originally defined, are shown on the maps of H.M. Geological Survey. We shall discuss the origin and sequence of these lower terraces in the following chapter.

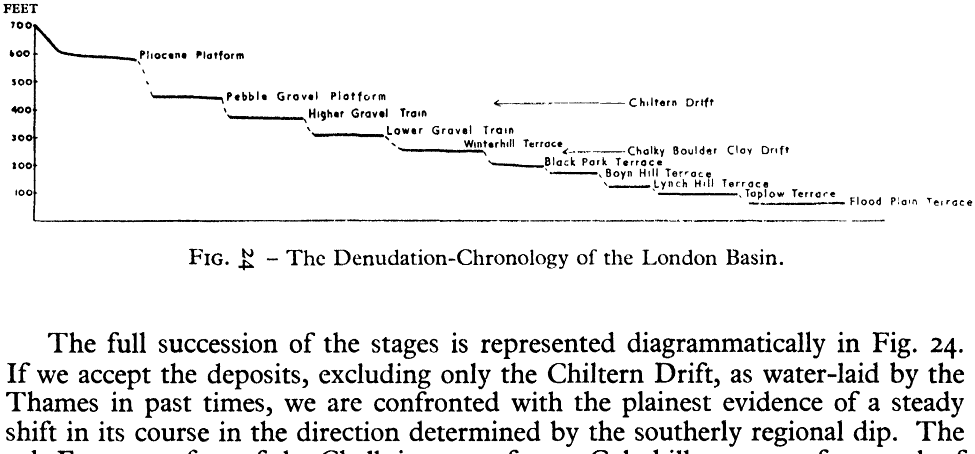


FIG. 24 – The Denudation-Chronology of the London Basin.

The full succession of the stages is represented diagrammatically in Fig. 24. If we accept the deposits, excluding only the Chiltern Drift, as water-laid by the Thames in past times, we are confronted with the plainest evidence of a steady shift in its course in the direction determined by the southerly regional dip. The sub-Eocene surface of the Chalk is at 400 feet at Coleshill, at —100 feet south of Windsor and it continues to fall southwards towards the centre of the synclinal trough, north of Woking, where it is below —500 feet (Fig. 5). The process of uniclinal shifting is thus by no means complete and it is significant of the continuance of the process that the Thames hugs the southern edge of its flood-plain to-day between Bray and Egham.

(iii) THE DRAINAGE OF THE PEBBLE GRAVEL PHASE (STAGE I)

We have stated that the gravels near Chalfont St. Giles, occurring below the level of the Pliocene shelf, but above that of the main mass of drift with Triassic debris, represent the earliest known fluviatile deposits of the Lower Thames system. This conclusion could certainly not be justified upon the local evidence alone, but the deposits, and the plateau surface with which they are associated, are displayed to great advantage in the country north of London, and in this tract their relations may be fully established.

Along the northern edge of the London Basin, the Eocene outcrop presents on the whole a featureless boundary. East of the Lea valley the Eocene margin is buried beneath glacial deposits, and west of the Colne valley it is for the most part obliterated by widespreading gravel plateaux, pertaining to Stage II as here defined. Between the Colne and the Lea, however, the London Clay rises above the low-ground of the Vale of St. Albans in a prominent range of hills, extending north-eastwards for 20 miles, from near Rickmansworth to Ware. The north-western edge of this upland is often referred to as the 'Tertiary escarpment', but close inspection reveals few of the characters of a true escarpment. There is no dip-slope, the area behind the crest being rather a level-topped dissected plateau of roughly triangular plan, with its south-eastern apex at High Barnet. The main ridge of high ground, now far from continuous, runs from Batchworth Heath (359) in the west, through Oxhey (438), Bushey Heath (504), Elstree (478), Arkley (465) to High Barnet (410), maintaining throughout a direction a little north of east. At the last-named place there is a pronounced elbow, the crest turning north-north-east through Potters Bar and Bell Bar to Epping Green. Throughout this portion of its range it is very level-topped, rarely dropping below 410–420 feet O.D. At its western and eastern ends the plateau is narrow, but north-westwards from High Barnet it attains a breadth of six miles, including several detached masses of high ground, as at Shenley and Ridgehill. South of the main triangular plateau outlying tracts of the same plateau surface occur at Totteridge (410) and at Hampstead (440) and it is apparent that what has been termed the '400-foot platform' is a dominant feature throughout the Middlesex and South Herts region.

Northwards, beyond the Vale of St. Albans, a similar 400-foot platform is developed on the lower parts of the Chiltern dip-slope from the neighbourhood of Welwyn, southwards to the Misbourne valley, and isolated remnants of the same surface are preserved in the summits of the Eocene outliers at St. Albans, Ayot and Burnham Green.

Eastwards, beyond the lower Lea valley, the summit-surface of Middlesex and Herts is evidently continued in the flat top of the Epping Forest ridge and of the high ground around Ongar, Brentwood and Billericay, but in this region the surface is everywhere below 400 feet (370–325 feet). Farther east the Laindon Hills preserve an isolated plateau summit at 378 feet.

West of the Colne valley the plateau surface is much less completely preserved. Apart from the narrow ledge on the Chiltern dip-slope already noted (p. 101), we have only the summits of the Wargrave Hills (Ashley Hill 475, Bowsey Hill 450 feet) and the high ground of Easthamstead Plain and Bagshot Heath which just exceeds 400 feet in elevation.

At nearly all the localities mentioned above, the summit-surface is underlain by a thin sheet of pebbly gravel. We have thought it well, however, to emphasize first the surface rather than the deposits, for the essential unity of the former can be appreciated at once from a contoured map of the region, while the deposits, mapped over a long term of years by the Geological Survey, appear quite naturally but rather misleadingly in a number of distinct local categories. But apart altogether from the deposits, the surface itself clearly requires explanation. It is certainly not a coincidence that all the higher hills of the central tract of the London Basin – a region of soft and incoherent rocks – show not only an accordant summit level, but are plainly bevelled. It is true that not quite all the summits mentioned above can be regarded as parts of one surface. The high ground from Bushey Heath to

Barnet Gate retains as we have seen a thin cover of Pliocene deposits (distinct from the true Pebble Gravel, but included with it on the maps of the Geological Survey) and projects above the surface of the Pebble Gravel plateau which is present on all sides save the south. Again, the elevated summits of the Bagshot country lie so far west of London that their height is hardly great enough for correlation with the Pebble Gravel surface; as noted below they appertain to a somewhat later stage (p. 106). For the rest, there is little doubt that we are dealing with one surface, covered with essentially contemporary deposits. It declines gently eastwards between the Wargrave Hills and Billericay at a rate of less than three feet per mile. The transverse gradients of the surface, so far as they can be measured, are so slight as to be almost negligible (Fig. 25A). Between Hampstead and Leverstock Green, near Hemel Hempstead, a distance of 18 miles, the surface passes from Bagshot Sands across the London Clay on to the Chalk, and the whole of its differences of level are comprehended within a vertical range of 30 feet or less. It is perhaps not without significance, however, that the elevations at the two ends of this line are slightly greater than in the central area around Barnet. Similarly, the surface at the Laindon Hills is slightly higher than at Billericay, etc.

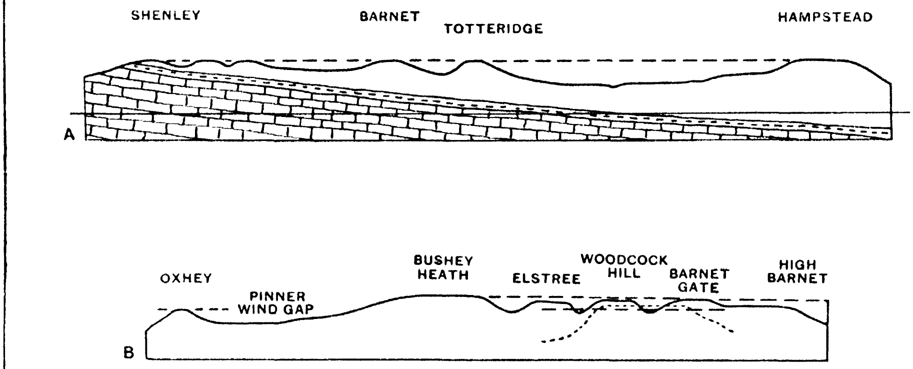


FIG. 25 – The Pebble Gravel Platform north of London. A. Section from N.W. to S.E., showing flat-topped hills at 400 feet, capped with Pebble Gravel. B. Section from W. to E. showing breaches in the Pebble Gravel ridge between Pinner and Barnet. The lower dashed line shows Pebble Gravel platform; upper dashed line shows Pliocene marine bench.

It is no part of our present purpose to review the long history of discussion concerning the purely geological problems of the Pebble Gravel.[21] There has been wide divergence of opinion concerning both the origin and the age of the deposit. For the geomorphologist the question of the precise age is not of first importance, but nevertheless, sufficient evidence is now to hand to afford us virtual certainty on this point. The general nature of the question is very readily grasped. If we seek for analogues of the Pebble Gravel in East Anglia we shall certainly conclude with Prestwich,[46] and Solomon[47] that they are to be found in the Westleton Shingle (p. 45). Alternatively, if we attempt to assess the age of the deposit by local evidence, we note at once that the Pliocene beds on the margins of the Basin must

have crossed, its central parts at a level little, if at all, above that of the present higher hill-tops, and we are thus led to enquire, with Barrow,[48] whether the Pebble Gravel is not simply the floor deposit of the Pliocene channel. It has been shown, however, that the petrographic features of the Pebble Gravel differ from those of the Pliocene beds, though they contain elements derived from these beds. On the other hand, the Pebble Gravel is in all essence petrographically identical with the Westleton Beds. Furthermore, wherever they occur in close juxtaposition, the Pebble Gravel surface is definitely below that of the Pliocene beds, as near Coleshill (p. 101) and Stanmore, and this confirms the conclusion that the Pebble Gravel is a younger deposit. While the Pliocene beds were referred to the Diestian (Older Pliocene) stage, it was possible to regard the Pebble Gravel as itself a Newer Pliocene deposit, but now that we have realized the probability that the local marine Pliocene beds are not older than the Newer Pliocene, no valid objection can be made from the physiographic side to the claim that the Pebble Gravel is Lower Pleistocene (Westleton Beds). This is far from saying, however, that the whole of the Pebble Gravel is necessarily marine. The Westleton sea of East Anglia must have reached a coastline somewhere to the west, and river-borne debris must have been carried into it across a contemporary land-surface, i.e. the marine Westleton Beds necessarily had fluviatile equivalents and parts of the Pebble Gravel might well represent such equivalents. There are excellent reasons for concluding that this is the case.

In the main Pebble Gravel area of South Herts the deposits are thin (rarely more than six feet) and poorly exposed. Study of the area has established one remarkable fact of outstanding importance to our present theme. A distinction can be drawn between the gravels on the eastern side of the plateau which yield abundant Lower Greensand chert and those on the western side which do not. The line separating the two types can always be laid down to within a few hundred yards and sometimes even more exactly. It runs from west of Barnet, via Potters Bar and Newgate Street, to Epping Green. There is a similar eastern margin to the chert-bearing gravels, for they are in close juxtaposition with chert-free gravels near High Beech and Jacks Hill on the Epping Forest ridge, and also at Coopersale Common. Chert in the Pebble Gravel is thus confined to a well-marked belt, four to five miles wide trending from south-west to north-east across the region. The same type of relationship may be inferred in southern Essex, for chert is completely absent in the hill-top gravels around Brentwood, but abundant in those of the Laindon Hills. Here is a plain indication of another chert-belt though absence of evidence prevents our defining its precise limits (see Fig. 11, p. 46).

Most of the constituents of the Pebble Gravel are local, in the sense that they were gathered within the Chalk escarpment (flints from the Chalk and Eocene flint pebbles). The ubiquitous small white quartz pebbles which are common north of London were shown by Barrow to be derived from the northern outcrops of the Lower Greensand in Bucks and Beds. The latter contains no chert, however, and this must have been derived from the Hythe Beds of the Wealden Lower Greensand. In the light of this fact the importance of the relations we have noted will immediately be seen. On the hill-tops, 10–20 miles north of London, we find commingled suites of debris, of northerly and southerly provenance respectively. It is not easy to assume that the transport of the quartz pebbles and the chert could have been effected by marine agency, and the localization of the chert in belts is definitely inimical to such a view, especially in view of the significant

fact that the concentrations of chert are opposite the points where the Mole and the Darent respectively enter the London Basin. It cannot be doubted, indeed, that in the Pebble Gravel phase we obtain a glimpse of the drainage system of the post-Pliocene proto-Thames and its tributaries. That such a system must have come into being with the emergence of the Pliocene sea-floor we can deduce on general grounds. What is surprising in the reconstruction is the markedly eccentric position of the trunk stream, in relation to the structure of the Basin. The facts recorded above and represented in Fig. 11 clearly imply that it followed a line not far from that of the present Vale of St. Albans, and its southern tributaries carried chert across the line of the present Lower Thames valley, not then in existence. The further north-easterly course of the main proto-Thames cannot be traced in detail for it leads into the lowland boulder-clay tract of northern Essex. We cannot doubt, however, that it flowed into the Westleton sea of East Anglia. Its course was determined either by that of the deepest part or axial line of the former Pliocene channel or by very slight differential movements accompanying the post-Pliocene uplift. The neighbourhood of its confluence with the proto-Mole is indicated by the first chert-belt. The proto-Darent joined it farther east, but it is possible that the proto-Medway flowed independently into the North Sea of that date. The wide extent of the Pebble Gravel surface suggests that it may have been formed in a phase of prolonged lateral river planation following the first slight uplift of the Pliocene sea-floor. Alternatively, the main sheet of quartzose gravels may be marine in origin, the chert-belts marking the course of the first rivers established on the emergent sea-floor.

(iv) THE DRAINAGE IN STAGE II – FORMER HYPOTHESES

We have seen that the deposits of Stage I – the Pebble Gravel – interpreted as fluviatile deposits, enable us to make a tentative reconstruction of the drainage plan of the London Basin at a time when the ancestor of the Thames followed a course well north of its present line. In turning to the deposits of Stage II to carry on the record we are confronted with perhaps the most difficult problem in the geomorphology of the whole region. The deposits of this stage are in large part those shown on the maps of the Geological Survey as 'glacial', 'fluvio-glacial', or in some cases as 'plateau' gravels, and coloured on the maps in a shade of pink, north of the Thames, and at a few localities south of, but close to, the river. They are characterized by Triassic debris, chiefly Bunter quartzites and pebbles of vein quartz, felsite, etc., which can also be matched in the Bunter Pebble beds of the Midlands. In Surrey and Berkshire, plateau gravels belonging to the same denudation stage occur, but they are of southerly provenance and Triassic debris is of necessity absent. In Herts and western Essex these gravels are associated with, and in part pass beneath, the great sheet of Chalky Boulder Clay.

The distribution of the main mass of gravels with Triassic debris is clearly seen in the Frontispiece and Fig. 28. They form a broad belt entering the district near Goring gap and traceable thence north-eastwards to the neighbourhood of St. Albans, beyond which they begin to pass under the Chalky Boulder Clay. In the western part, this belt follows the line of the River Thames, but lies chiefly north of it and is thus in close juxtaposition with the Stage III or terrace gravels. From Maidenhead, however, the Thames flows south-eastward and the Stage III deposits diverge from the main mass of the Stage II deposits. East of the Colne the two gravel-belts are separated by a strip of country nearly 10 miles wide. In

1912 Sherlock and Noble[49] suggested that these relationships could be explained on the hypothesis that the pre-glacial Thames flowed north-eastwards from the neighbourhood of Reading at the foot of an Eocene escarpment and thus failed to enter the central tract of the London syncline. They held that the river had later been diverted by ice advancing athwart its course between Bourne End and Rickmansworth and that overflows were initiated on either side of the ice-lobe, developing in due course into the present valleys of the lower Colne (below Rickmansworth) and of the Thames between Bourne End and Maidenhead. Twelve years later Sherlock[50] returned to the subject, tracing the line of the supposed pre-glacial Thames onwards from Watford to Ware. He demonstrated the existence of a drift-filled channel below the present floor of the Vale of St. Albans and argued that this channel marked the former line of the Thames.

As regards the course of the river beyond Ware, Sherlock at first thought that it turned through the great bend at Amwell into the present lower Lea valley. Later he concluded, however, that the Amwell gorge was essentially a spillway comparable with those near Rickmansworth and Bourne End and he was led to suggest that the ancestral Thames pursued its course at the foot of the Eocene escarpment towards Bishop's Stortford, escaping thence northwards into the Wash by way of the well-known drift-filled channel at the head of the Cam.

In the view of the present writers, Sherlock's theory is, in essence, sound, though long study of the ground has led us to conclusions which differ in detail, if not in principle, from those he reached. Since Sherlock wrote there has been little published comment on his views, though other authors have pursued their own lines of reasoning based essentially on independent premises. A study of the literature indicates little or no convergence toward an agreed view. We may note here certain other published views on the development of the Thames drainage system.

In 1922 there appeared a privately printed account of the rivers of Essex by Professor J. W. Gregory.[51] He discussed the general drainage development of a wider region and dealt *inter alia*, with the distribution of pebbles of the highly distinctive *Rhaxella* chert, as affording important index to former drainage lines. In a reconstruction of the drainage for a date not exactly specified, but broadly contemporary with that of Sherlock's pre-glacial Thames, he inferred the presence of two independent major streams draining eastwards across the London Basin; (a) the ancestor of the present Lower Thames through London, and (b) a stream following the line of the Ouse headwaters, the upper Lea and the Chelmer. The latter stream was regarded as responsible for introducing *Rhaxella* chert† into certain plateau gravels in western Essex. It will be seen that from near Hatfield to beyond Ware, this river followed the line of Sherlock's pre-glacial Thames, but beyond, it was regarded as following the broad depression, now drift-covered, which crosses central Essex towards the Blackwater estuary.

In 1922 Professor H. L. Hawkins[52] communicated to the British Association at Hull still other suggestions on the drainage pattern of the Lower Thames region. He called attention to the fact that the great Henley-Maidenhead loop, in which the Thames is incised deeply below the Chiltern dip-slope, recalls in its form a

† *Rhaxella* chert occurs over a limited area within the Corallian Beds near Arngrove (Bucks) and also in the Corallian of West and East Yorks. The varieties from these localities are said to be distinguishable. Far-travelled pebbles of this material are thus amongst the few of which the precise place of origin may be regarded as known.

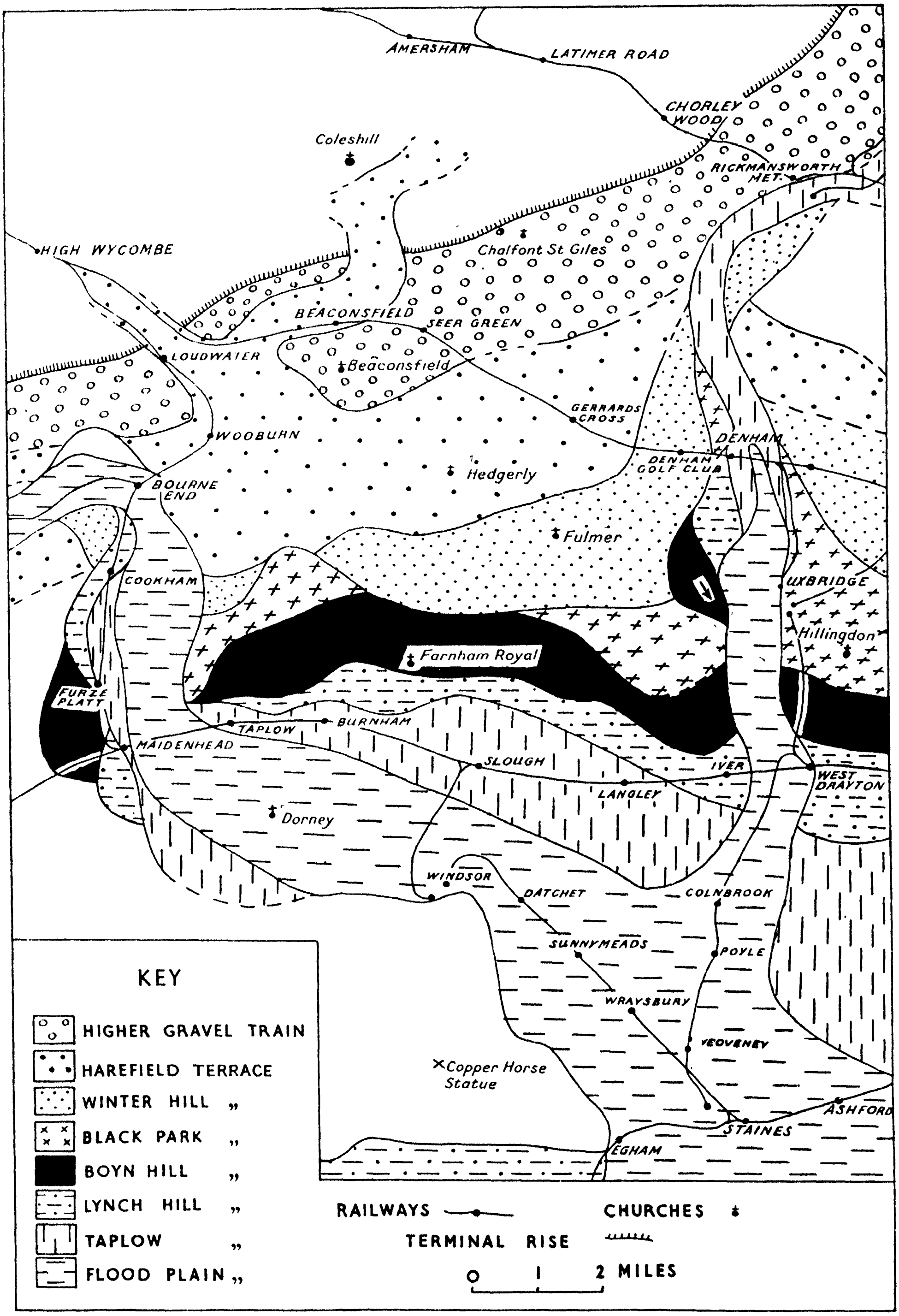


FIG. 26 – The Terraces of the Middle Thames Valley.

smaller loop, west of Reading, recently partly abandoned. Study of the map makes it clear that in the recent past the Kennet flowed northwards from Theale to join the Thames at Pangbourne, receiving the River Pang as a west bank tributary. It has since been diverted to its present confluence with the Thames, leaving the southern part of its former valley deserted, while the northern part is occupied only by the diminutive Pang. Hawkins further pointed out that the valleys of the Colne and of the middle and lower Lea constitute another but larger loop on the same plan (Figs. 18, 28). Accordingly he made the bold suggestion that at a former, and presumably pre-glacial, date, and at a level considerably above the existing valley floors the Thames flowed 'up the Colne and down the Lea', thus traversing the third of a series of meanders which increased in size downstream.

It is likely that an investigator encountering any of the foregoing theories for the first time, might be persuaded of their essential truth. But plainly they cannot be all true unless they are to be regarded as successive stages in one evolution. Further, closer examination would, in any of the three cases, suggest unanswered questions, particularly in regard to the dates of the several episodes imagined and the heights of the various sheets of river – or glacial – drift involved. The latter we believe is the crucial consideration, but little attention was devoted to it by any of the investigators named. Taking Professor Hawkins's suggestion for instance, it would be almost proved if a gravel train, falling *northwards* could be discovered near the lower Colne valley. There is, we believe, no such train, so that if it existed, it must have lain above the highest local hill-tops or alternatively must have been completely destroyed at lower levels. Professor Gregory's 'Ouse-Lea-Chelmer' river also creates problems. The case for its existence cannot rest on the occurrence of *Rhaxella* chert in Essex. Professor Gregory was unaware that *Rhaxella* chert occurs in the older Pebble Gravels as at Oxhey, and could pass thence into any later accumulations. Further, *Rhaxella* chert from the type locality near Arngrove could have entered the Basin via Goring gap and, indeed, the pebbles of it occur in the Triassic drift west of the Lea. Further, the question arises: what was the relation of the Ouse-Lea-Chelmer to the drifts which lie in its course between Hatfield and Ware? Did it pass above or below their present site, or was the river itself responsible for depositing any part of them? In the view of the present writers, Dr. Sherlock's views approach much more nearly to the truth than those of Gregory and Hawkins, though the record of events proves much more complex than he supposed.

(v) ANALYSIS OF THE STAGE II DRIFT BELT

It will be noted that without exception the above-mentioned writers tacitly treated the 'glacial' gravels as essentially one and indivisible. We have already indicated that they are, in fact, divisible into distinct terraces or gravel trains. The first clear recognition of this fact was due to H. J. Osborne White[53] who, writing more than half a century ago, claimed that the glacial or plateau gravels continued the record of the acknowledged terrace stages upwards in elevation and backwards in time. Later, he indicated the existence of definite terraces in the 'Stage II' drifts in the area around Henley.[54] A continuance of the line of investigation – essentially morphological – initiated by Osborne White has led us to definite conclusions concerning the evolution of the Lower Thames drainage system after the Pebble Gravel Stage.

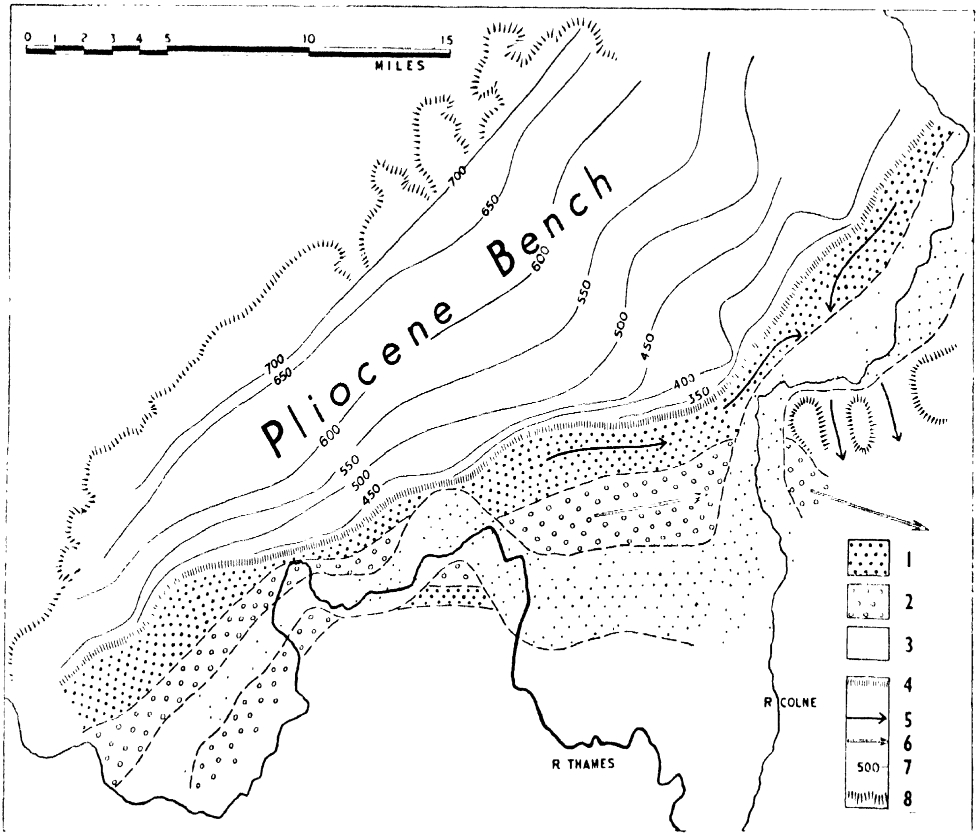


FIG. 27 – The Stage II drifts in the Middle Thames area. 1. Higher and Leavesden Gravel Trains. 2. Lower Gravel Train. 3. Winter Hill Terrace. 4. The 'Terminal Rise' which bounds drift belt on north. 5. Directions of drainage at stage of Higher Gravel Train. 6. Directions of drainage at stage of Lower Gravel Train. 7. Generalized contours on Chiltern dip-slope. 8. Edge of masses of high ground (bringing out wind-gaps).

The Stage II drift belt may be considered conveniently in two main sections lying respectively west and east of the lower Colne valley.

a. *The Western (Middle Thames) Area*

In an earlier survey one of us recognized three main terrace stages in this area;[55] they were termed the Higher Gravel Train, the Lower Gravel Train and the Winter Hill Terrace. In a later and more detailed examination of the country around Beaconsfield, F. K. Hare[56] renamed the Lower Gravel Train the Harefield Terrace and the feature is there well enough developed to merit this name. Elsewhere the name is not so readily applicable since there appears to be a series of related terraces at about this height which can be conveniently grouped under the wider term. We have already noted Hare's demonstration that, as had been suspected, the Winter Hill stage was itself composite. He was able to distinguish a lower terrace with its surface some 50 feet below that of the Winter Hill Terrace; this he called the Black Park Terrace. This is separately distinguished in Fig. 26, based upon Hare's detailed mapping, but it has not yet been traced throughout the rest of the Middle Thames area and is accordingly included with the Winter Hill stage in Fig. 27.

The chief terrace stages known in the Beaconsfield country are traceable as far west as Goring gap. The Higher Gravel Train is present on both sides of Goring gap; eastwards it is continuously traceable on the north side of the Thames valley to the neighbourhood of Bourne End and thence, as we have seen, across the Beaconsfield gravel plateau. It reappears on the south side of the Thames above Cookham Dean. Its level falls eastwards as may be most readily appreciated by studying the behaviour of the well-marked 'rise' behind the gravel spread. The base of the rise is at about 350 feet in the Beaconsfield country, about 400 feet north of Marlow, and near 450 feet north of Reading. It is, indeed, a continuous feature inclined eastwards at an average rate of about six feet per mile. In the area north of Reading there are no large masses of drift above this feature, though ill-defined tracts of stony clay occur and some at least of the ground mapped as Clay-with-Flints is probably of this nature.

The Lower Gravel Train is widely developed south of Beaconsfield, but on the flanks of the 'Henley loop' later erosion has largely destroyed it. In unpublished work Mrs. C. E. Sealy has applied Hare's methods of mapping in this area and recognized both the Harefield Terrace and a lower 'Rassler Terrace' prominent at about 300 feet west of Marlow. The two stages are nowhere in contact so that it is impossible to be certain that they were anywhere separated by a distinct break of slope. It is because of such doubts that it remains preferable at present to retain the term Lower Gravel Train in a wider survey, while recognizing that it is certainly composite. West of Henley the Lower Gravel Train can be identified over a broad belt ranging westwards to Goring gap and the feature behind it is plainly marked. It is recognizable also on the high ground of Binfield Heath and Shiplake Row and is traceable also west of Reading. Like its higher analogue it falls in level eastwards though at a slower rate.

The Winter Hill stage is present in the 'Henley loop'. The corresponding gravels floor a trough cut within the Lower Gravel Train between Henley and Reading and are evidently equivalent to the Silchester Terrace of the Kennet valley. In the former area the late Llewellyn Treacher collected large numbers of flint implements and recent work upon these by Arkell and Oakley[57] has shown that these constitute an important assemblage comparable with that of the 40-metre terrace of the Somme. They indicate a date definitely earlier than that of the implements of the Boyn Hill Terrace and probably belong to the First Interglacial period. We shall discuss some of the bearings of this important correlation below: for the moment it is sufficient to notice that the suggested date is consonant with the local evidence to the extent that the deposits are clearly later than the Chiltern drift which embodies evidence of the first recorded glaciation of the area.

The terrace sequence of the Stage II drifts is inevitably incomplete and obscure locally. Where the deposits rest on Chalk they have been affected in some degree by sub-surface solution and they have been widely subject to surface-creep or solifluxion. These facts certainly do not warrant the assumption that the gravels as a whole form a sloping sheet. Their great range of height would in any case preclude such an assumption, which would be little better than a physiographic absurdity. In actual fact the main lineaments of a terrace sequence are preserved with great consistency. The record may certainly be more complex than our scheme suggests; minor terrace stages appear to be indicated in places, but they cannot be traced far. To this extent the Higher and Lower Gravel Trains are no doubt composite, and for this reason we have preferred the term 'gravel-train'

to 'terrace'. The Winter Hill Terrace may also be composite, but it behaves on the whole as a high terrace of the Thames and justifies its name.

In a broad sense at least there can be no doubt that the several stages represent successive episodes of erosion and down-cutting, followed by deposition, in the Thames valley, and their mutual relations are sufficiently consistent to enable a reconstruction as shown in Fig. 27. At the time of the Higher Gravel Train the Thames entered the London Basin at Goring gap and followed a north-easterly course slightly oblique to the general regional strike. We can hardly doubt that in the preceding Pebble Gravel stage a similar course was followed. The Lower Gravel Train lies southward of the Higher Gravel Train in both the Reading and the Beaconsfield districts and we conclude that the Thames had been subject to uniclinal shifting in both areas. In the intervening tract of the Henley loop no such shifting took place; the Lower Gravel Train lies within the area of the Higher Gravel Train. This difference arises from the fact that the Thames was here cutting in Chalk; eastwards and to a less extent westwards it was cutting in Eocene beds. At the Winter Hill stage we have evidence of the initiation of the great meander of the Henley loop, for it is impossible to connect the gravels at Winter Hill with those north of Taplow, without assuming a considerable bend in the river's course. It appears therefore that this feature arose normally and gradually without the intervention of any form of glacial diversion. West of Henley, on the other hand, the Winter Hill course of the Thames lay outside the limits of the present valley, being entrenched below the Lower Gravel Train between Henley and Caversham. This high-level trench thus represents an ancient abandoned incised meander of the Thames.

b. *The Eastern Area (Vale of St. Albans)*

The drift-belt of the Vale of St. Albans appears to be the direct continuation of the great composite gravel train we have traced eastwards from Goring Gap. Such a relationship, however, is more apparent than real. If we seek to trace the western gravels into their supposed eastern counterparts along the axis of the combined drift-belt we are confronted by a sharp and inexplicable break of profile west of Rickmansworth. Around Heronsgate, the gravels of the Higher Train are between 300 and 350 feet O.D., but at Croxley Green, less than two miles to the east, the surface of the apparently continuing spread is barely above 250 feet. Any attempt to link the two spreads thus presents us with a sharp declivity, for which there is no parallel either eastwards or westwards. We cannot evade the difficulty by assuming that the gravel train has been disjointed by faulting or sharp flexuring, for the attitude of the local Eocene deposits demonstrates the absence of any such structure. While these facts effectively oppose the simple and direct correlation of the main masses of the western and eastern gravels respectively, they by no means prove that no correlation can be effected. The great range of height of the drifts in the Vale of St. Albans suggests, as in the western area, that the drift cover is composite, a suggestion strongly enforced by the terraced conformation of the drifts.

The following succession can be recognized (Fig. 28):

1. The Chiltern Drift (p. 101). This comprises wide expanses of stony clay locally associated with gravels, and is best seen in the belt of country south and east of Chesham. In large part, the constituents of this drift are local, but along the south-eastern margin of the belt Triassic debris is abundant. There can be little doubt

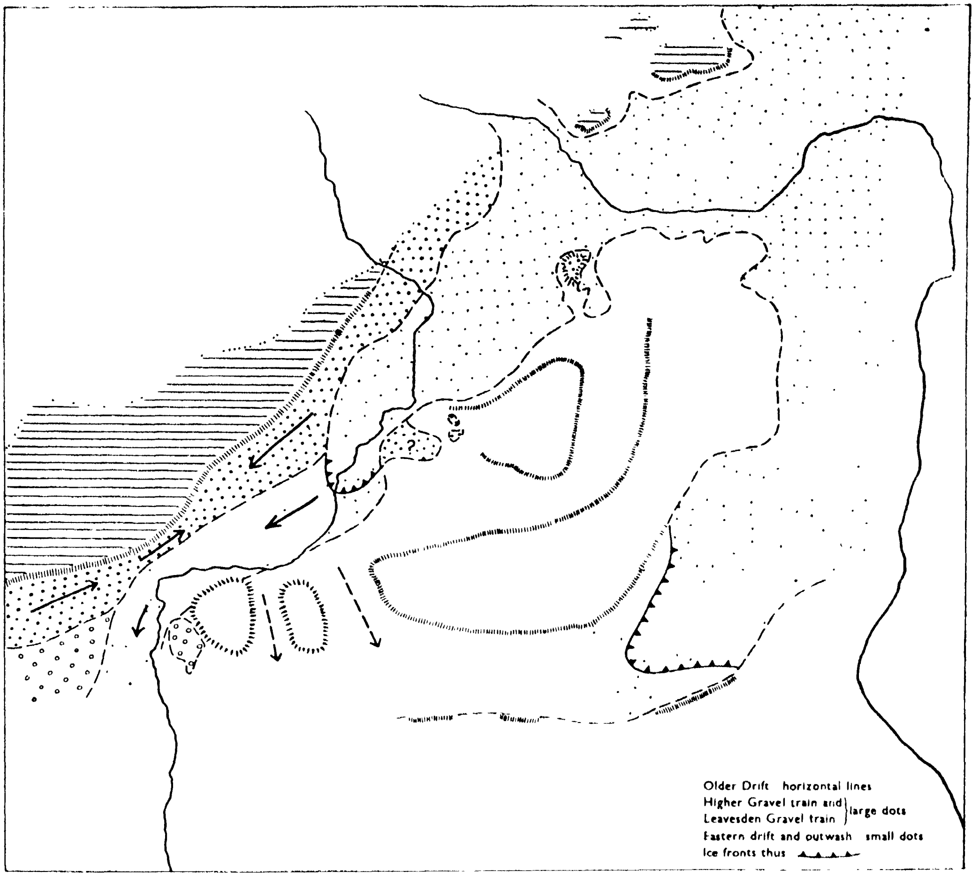


FIG. 28 – The Stage II drifts in the Vale of St. Albans (the Lower Gravel Train, shown in small circles is seen on the western side of the area). Note: for Older Drift read Chiltern Drift.

that the drift is the product of an ice-sheet moving southward or south-eastward. The ground-moraine of the ice-sheet involved local debris only, except where it impinged upon a pre-existing gravels with Triassic debris along its southern edge. This fact is important and its significance is discussed below (p. 117).

2. The southern limit of the Chiltern Drift is marked by a pronounced feature or break of slope, well seen south of Micklefield Hall and Langleybury, and traceable thence eastwards past Abbots Langley and Bedmond. Below this feature is a broad terrace-like expanse of gravels and clays which we have termed the Leavesden Gravel Train. It falls in level *westwards* from 330–350 feet near St. Albans to 280–300 feet north of Watford.

3. The Leavesden Gravel Train is separated in its turn by a well-marked feature from the main mass of glacial drift, here termed the 'Eastern Drift', which occupies the floor of the Vale of St. Albans. The geological features of the deposits are well known and have been fully described, but we must devote particular attention here to their physiographic relations as a whole.

It is evident that the Eastern Drift advanced into a countryside which had already taken on the main outlines of its present form (Fig. 28). The main ice-sheet, overriding the crest of the Chalk escarpment east of Hitchin, moved in a southerly and south-westerly direction down the dip-slope of the Chalk, until it split upon the angle of the high ground south of Ware, sending one ice-lobe south-westwards to Aldenham, and another, south of the main Pebble Gravel plateau, to Finchley. At the eastern end of the Vale of St. Albans the drift of the Aldenham ice-lobe is largely below 300 feet (surface level) though locally it extends higher. In the west of the Vale the surface of the drift is everywhere below 300 feet. The height of the sub-drift surface is known at a number of points; in the central parts of the Vale it rarely departs far from 200 feet. The physiographic relations of the Finchley ice-lobe were similar. North and west of Enfield the deposits rest on a gentle slope inclined eastwards. The surface of the boulder-clay is at 230 feet at Enfield and 290 feet north of Chase Side. At Finchley the ice occupied a broad depression between the high ground at Hampstead and Barnet respectively; the surface of the boulder-clay varies in height from 250–300 feet and the sub-drift surface is at 224 feet at Church End, Finchley.

The outwash gravels of the Aldenham ice-lobe are traceable down the Colne valley and it is difficult to avoid the conclusion that they must be merged with those of the Winter Hill Terrace around Gerrards Cross and Iver. Similarly the outwash gravels of the Finchley ice-lobe are disposed somewhat above 200 feet at Hendon, and elsewhere in the Brent valley, and they must have entered the Thames valley at about this level.

It is clear from these facts that the drift-filling of the Vale of St. Albans includes three elements distinct from each other to the extent that they rest on different surfaces separated by continuous breaks of slope. We conclude, further, that the following correlations can be made with the country to the west:

Leavesden Gravel Train	=	Higher Gravel Train
Eastern Drift	=	Winter Hill Terrace or Black Park Terrace

The first correlation depends upon the fact that the feature marking the northern boundary of the Leavesden Gravel Train directly continues the 'terminal rise' of the western country though *it falls in the opposite direction* (Figs. 27 and 28). The second follows from the general correspondence in level between the Eastern Drift outwash and the Winter Hill or Black Park Terraces. It is particularly to be noted that no equivalent of the Lower Gravel Train can be traced in the Vale of St. Albans and that at the stages both of the Leavesden Gravel Train and the Eastern Drift the drainage of the western part of the Vale was towards the *west*.

It is evident that these facts present us with a complex problem of drainage evolution and no solution to the problem can afford to ignore certain salient physiographic features of the area, of which we have as yet made no mention.

West of Hatfield the so-called Tertiary escarpment is breached by a number of gaps. The small high-level gaps near Arkley and Borehamwood are probably nothing more than valley-head embrasures or recession-cols, but this is certainly not true of the larger gaps of the district. Chief amongst them are the two broad wind-gaps traversed by the railway lines to Watford and Rickmansworth respectively. These are well developed features evidently of considerable age. Their floor-level (*c.* 250 feet) is definitely above that of the surface of the Eastern Drift to the north. The floors are drift-free, but in both gaps there are dissected relics

of a higher and older floor at about 300 feet, and in the western gap there are two small outliers of gravel at this level south of Northwood. It would seem at first sight that we are here confronted with a simple case of river-capture and this appears to have been the view of W. M. Davis[19] and A. Sutton.[58] A simple drainage map suggests that the lower Colne has beheaded streams now represented by the Gade and the upper Colne which formerly flowed through the two gaps. We shall find that the process was more complicated than this, but for our present purpose the main conclusion stands that the gaps were not abandoned by *southward* flowing drainage lines until shortly before the arrival of the Eastern Drift. There must therefore have been a drainage *across* the line of the Vale of St. Albans at the 250-foot and higher levels. If this conclusion is sound it completely opposes the assumption of an eastward-flowing through-drainage *along* the line of the Vale of St. Albans except at some very early date, corresponding to the deposits of the hill-top levels – i.e. Pebble Gravel or Chiltern Drift. In other words, the presence of these gaps must render invalid any attempt to carry the western gravel trains eastwards into the Vale of St. Albans. Regarding matters from this point of view we obtain at once a striking confirmation in the fact that the Higher Gravel Train and the Leavesden Gravel Train meet at their common lowest point (*c.* 280 feet), near Redheath, exactly opposite these gaps (Fig. 28).

Farther east, breaches in the Tertiary escarpment, near Radlett and Hatfield respectively are linked by a 'loopway' trench, cut in London Clay and passing through North Mimms, South Mimms and Bricketwood.[59] It is drained northwards at its two ends by affluents of the River Colne, but its form and relations suggest that it came into being as a whole during some past drainage episode. Later dissection has modified it to some extent. The floor-level north of Arkley, where it is but little dissected, is 327 feet. Regarded as a channel of a former through-drainage it seems probable that the original floor-level descended from rather less than 350 feet at the western end to about 300 feet at the eastern end, but it is impossible to be certain of these figures.

There is a further feature in the physiography of Middlesex which is of the highest importance in reconstructing the drainage evolution. We have seen that the Eastern Drift of the southern or Finchley ice-lobe rests on the floor of a broad depression between Hampstead and Barnet. The outwash extends south-westwards into the area of the present Brent valley, but study of a contoured map conveys a clear suggestion that the major depression continued westwards, between the high ground of Mill Hill and Stanmore on the north and that of Harrow and Kingsbury on the south. Later dissection by minor streams in this readily-eroded clay country has gone far to obliterate the former continuity of the trough, but its main outlines remain visible. There seems little doubt that it was by way of this trough that the Lower Gravel Train of the western country passed eastwards. We have seen that it has no representative in the Vale of St. Albans, though it is traceable across the Beaconsfield plateau as far as the western confines of the Colne valley. On the eastern side of the latter, at Harefield, is a mass of gravel which undoubtedly continues the Lower Gravel Train. At first sight it appears that this gravel sheet falls in level northwards, but this is not the case. The northern extremity is actually part of a lower and younger gravel mass (*c.* 260-foot surface level) – probably part of the Eastern Drift outwash. The main mass of gravels at Harefield falls in level in a south-easterly direction, shaping a course which would have carried the gravel-train into the great Middlesex trough.

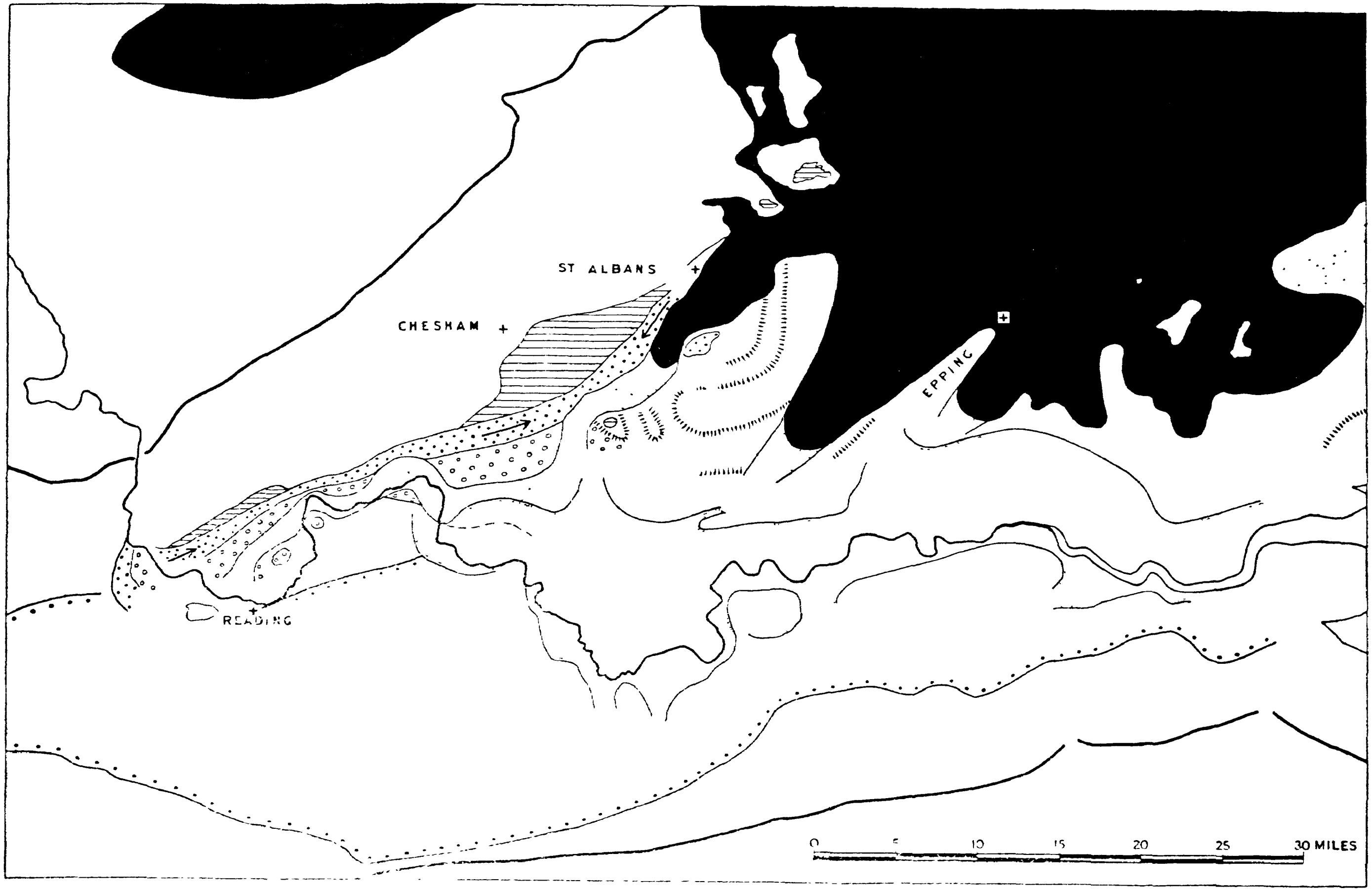


FIG. 29 – General map of the 'glacial' drift deposit in relation to the present and former valleys of the Thames. Legend as in Figs. 26 and 28. Ice-sheet in solid black. Boundaries of Chalk, Eocene beds, and lower level terrace drifts also shown.

A significant confirmatory indication of a former W.-E. drainage through this trough is found in the fact that the gravel cap of Horsendon Hill (278 feet), south of Harrow, contains abundant Lower Greensand chert, proving a former drainage towards the trough *across* the line of the present Lower Thames valley, as in the earlier Pebble Gravel stage.

The streams traversing the Watford gaps must have flowed into this great depression. As a whole it takes its place as a larger analogue of the Borehamwood-Mimms trough, linking, as it were, the two ends of the Vale of St. Albans.

(vi) THE SEQUENCE OF DRAINAGE CHANGES [55]

We are now in a position to attempt a co-ordination and interpretation of the above evidence in its bearing upon the physiographic evolution of the area. We have an established starting point in the Pebble Gravel phase during which the 'proto-Thames' followed a line near the present Vale of St. Albans. The next recognizable episode is that of the 'Chiltern Drift' and to the ice which deposited this drift we may attribute the first major glacial diversion of the Thames. It is highly probable, however, that before and during the earlier stages of the Chiltern Drift phase the Thames had begun to introduce Triassic debris. Only thus can be explained the fact that the Chiltern Drift contains such debris along its southern margin. Evidently there was no direct source of Triassic pebbles available to the Chiltern ice. They must have been introduced via Goring gap by the Thames, and their presence in the drift thus implies pre-existing river-gravels from which they could be derived. The following words of Sherlock, though applied by him to the area farther west, describe essentially the relation we have in mind. 'The ice-sheet, by the time that it had reached the Thames, had nearly approached its southern limit. The materials of the gravels would be mainly derived from the ice-sheet, but a certain amount and notably the Triassic pebbles would be introduced by the Thames in flood-time.'

If this reasoning is correct it implies that the Thames followed a line essentially as indicated by Sherlock as far east as Ware – practically the same line, indeed, as it followed in the Pebble Gravel phase. Our interpretation differs from that of Sherlock in regarding this as an early episode, separated by a long period of time from the Eastern Drift.

The stage of the Higher and Leavesden Gravel Trains is the first for which we can make any detailed reconstruction of the drainage. A confluence of eastward- and westward-flowing waters occurred near Croxley Green, and there can be no doubt that the combined stream escaped southwards in the vicinity of the Watford gaps.

It seems probable that this great change was effected by the advance of the Chiltern ice athwart the course of the old Thames in the neighbourhood of St. Albans. It is possible that the Borehamwood channel was initiated at this stage as a 'by-pass', but we are without detailed evidence to date it. Certain it is that the southward-flowing drainage near Watford must have been initiated at about this time and later evidences indicate that the waters then turned eastwards *via* the Finchley depression to regain their former line near Ware. It is probable that a relict stream continued to occupy the old line east of St. Albans, joining the diverted main stream near Ware. This conclusion is enforced by the fact that, before the advance of the Eastern Ice, the floor of the Vale of St. Albans had suffered considerable further lowering by river-action.

At the stage of the Lower Gravel Train we can trace the Thames from Goring gap eastwards to the Colne valley along a line lying consistently southward of its earlier course. We have given reason to suppose that it then looped southwards across Middlesex by way of the Finchley depression (p. 115). The Lower Gravel Train is broad, and its southern edge cannot everywhere be determined, but the approximate position of its median line is indicated at three points, viz. Shiplake Row, Collum Green and Horsendon Hill, by the occurrence of Lower Greensand chert brought in by southerly affluents.

We are without evidence of the precise cause of the southerly shift of the Thames course near Rickmansworth between the stages of the Higher and Lower Gravel Trains. Probably it represents no more than general 'uniclinal shifting' in accordance with the regional dip. It is permissible to infer that drainage through the Watford gaps continued for some time after the establishment of the new course, for the lowering of the gaps certainly continued. These southward-flowing streams were ultimately captured, before the advance of the Eastern Ice, not as the present map would suggest by the Colne, which did not then exist, but by the eastward-flowing stream relict of the first diversion. The evidence for this conclusion is the fact that, as shown by Sherlock, the floor of the Vale of St. Albans, beneath the Eastern Drift falls eastwards. The relict stream, initially heading near St. Albans, cut back so as to recover much of the ancestral course.

Thus by the end of the stage of the Lower Gravel Train the drainage plan had recovered the elements of the ancestral pattern, and a continuance of successful piracy by the eastward-flowing stream in the Vale of St. Albans might have completed the rectification, leaving the Middlesex loopway abandoned. A new complicating factor was now to hand, which produced very different consequences.

We have seen that the ice-sheet of the Eastern Drift advanced into a countryside which possessed in essence its present features of form *above the 200-foot level.* There is widespread evidence of a long-continued phase of semi-planation culminating in a plain at about this level, diversified by relict hills.[60] It should be noted that there is no evidence that the Eastern Ice in its marginal regions was an active eroding agent. It did not make the depressions in which it rested; essentially, it simply occupied them. It is this conclusion which lends such high importance to the Finchley depression, for the behaviour of the ice north of London shows conclusively that the Finchley depression *did* exist, while the lower Lea valley *did not* exist at the time of the ice advance. Dr. Sherlock noted the striking difference in the nature and form of the Lea valley above and below Ware and correctly inferred that the two portions were of very different ages. He wrote, however, before the revision of the geological map of the North London area and thus the relations of the Finchley ice-lobe could not be considered in his paper. With the whole of the facts now before us it becomes clear that a broad valley existed here before the advance of the ice and we have employed this evidence in defining the course of the Middlesex loopway at earlier dates.

The course of events following the advance of the ice is plainly written in outline at least. The ice-sheet sent forward two lobes which advanced against the direction of the drainage, in both the Vale of St. Albans and the Finchley depression, and in both cases the drainage direction was reversed. The outwash from the Aldenham lobe was carried westwards past Watford and Rickmansworth and thence *via* the Mill End gorge to the broad gravel plain south of Gerrards Cross, where it merged with the deposits of the Winter Hill stage of the Thames. It was at this

stage, therefore, that the lower Colne was initiated. The drainage from the Finchley lobe must have passed westward into the Thames valley, and in this episode we no doubt witness the initiation of the lower Brent valley. The lower Lea drainage seems to have been initiated during the retreatal or decaying phases of the Finchley lobe. The drainage line has slipped steadily eastwards during later times under the influence of a monoclinal fold.

CHAPTER IX

THE TERRACES OF THE LOWER THAMES VALLEY

In the Middle Thames area the lower terraces of the Thames continue the sequence of the higher terraces down to the present floor of the valley. East of the Colne, however, they part company with the higher members of the series and are widely developed in the Lower Thames valley between Staines and Gravesend. Here a clear distinction between the High, Middle and Low Terraces was early made: the two higher Terraces show very slight downstream gradients and it was possible to speak without serious ambiguity of the 100-foot and the 50-foot terraces, respectively. This nomenclature could not, however, avail further upstream or in the tributary valleys: it was in the Middle Thames area that H.M. Geological Survey first introduced the classification into Boyn Hill (100 feet), Taplow (50 feet) and Flood Plain Terraces,[61] and this was afterwards applied throughout the London district. Further study has somewhat elaborated the terrace sequence. The Taplow Terrace is certainly double and its upper leaf has been variously referred to as the Upper Taplow, Iver or (following Hare) the Lynch Hill Terrace. Upper and lower Flood Plain Terraces can also be distinguished locally.

More is involved, however, than the multiplication of terrace surfaces. In the Lower Thames area the deposits attain thicknesses of 40–50 feet, or even more, and it is clear that considerable episodes of aggradation have taken place. In the Middle Thames area, where the thicknesses are much smaller, it is at least conceivable that the terraces are simply flood-plains recording successive stages of 'uplift' or falling base-level. No such interpretation can avail in the Lower Thames region which shows the plainest effects of both positive and negative movements of base-level.

The evidence is wholly consistent with our growing knowledge of Pleistocene oscillations of sea-level brought about by the growth and dispersal of the ice-sheets. The existing ice-masses of the world represent water withheld from the oceans equivalent to a world-wide layer some 150–160 feet deep, i.e. their dispersal would cause a general rise of sea-level of this amount. The four-fold waxing and waning of ice-sheets during Pleistocene times must have been accountable for even greater oscillations. Such shifts of sea-level have necessarily been superimposed upon any other local or general movements of base-level which have been in progress, but these have not, in general, sufficed to obliterate the clear evidence of alternating high and low sea-levels during Pleistocene times.

In reading the older literature on the Lower Thames terraces it is important to recall the firmly held view of former days that there was only one glacial period represented in the British drifts. Though Penck and Bruckner had demonstrated the four-fold glaciation of the Alps during the first decade of this century and a similar sequence was abundantly demonstrated in the North German Plain and elsewhere, British authorities for long remained sceptical. In the London area the

one undoubted witness to the former presence of land-ice was found in the Chalky Boulder Clay. The relation of the Lower Thames terraces to this deposit was much disputed. Most workers treated the terrace deposits as 'post-glacial', resting their claims upon the 'warm fauna' of the High Terrace, the occurrence within it of what were regarded as glacially transported erratics, and the fact that it appeared to rest upon the Chalky Boulder Clay near Hornchurch, Essex. Since, however, the only truly 'cold fauna' in the terrace drifts came from the Low Terrace, some regarded this as fixing the date of the single glaciation of the region; the Middle and High Terraces were then, in the local sense, 'pre-glacial'.

Recent years have witnessed a radical change of view in Britain concerning the number and sequence of glacial periods. In 1932 J. D. Solomon[62] demonstrated the four-fold glaciation of East Anglia, and his succession can be satisfactorily correlated with the better-known sequence of northern Germany. Into the details of this correlation we need not here enter. It is sufficient to note that the older and higher drifts of the London area give evidence of two glaciations (the Chiltern Drift and the Eastern Drift). If therefore we accept the general four-fold scheme of glaciation and regard the Boyn Hill Terrace as later than the Chalky Boulder Clay, the terrace deposits themselves might be expected to embody the record of at least two further cold phases.

These considerations sufficiently indicate that a simple 'morphological' classification of the Lower Thames terraces which treats them as successive flood-plains cannot, taken alone, reveal the probable complexity of the record. The deposits themselves, their fossil contents, and their associated Palaeolithic flint implements need to be brought to the service of the argument. The fossil evidence has led, indeed, to very discrepant conclusions. Few of the animal groups chiefly represented reveal clear and indubitable evolutionary progress during the comparatively short Pleistocene interval. Accordingly they yield little definitive dating evidence, though, together with plant remains, they are a faithful reflex of climate. More success has been gained in dating the deposits by their included flint implements. The general sequence of culture stages is now adequately known and it can be brought into broad relationship with the succession of glacial and inter-glacial periods in Europe. Thus the primitive hand axes styled 'Abbevillian' are assigned to the period of the first glaciation and the following inter-glacial period. The succeeding Acheulian phase extends from early in the second inter-glacial period to beyond the third glaciation. The quite distinct tradition of 'Flake-tools' begins with the Clactonian phase: it is suggested that people with Clactonian culture (probably of Asiatic origin) entered western Europe at a time corresponding to the beginning of the second glaciation, but the culture continues throughout the succeeding inter-glacial period. The highly characteristic flake-tools of the Levallois tradition come in about the time of the third glaciation and persist throughout the last inter-glacial period.

These correlations, though not universally acceptable, rest on sufficient evidence to command respect, but they are of limited assistance in solving the problem of dating. They necessarily depend upon arguments which are in continual danger of begging the question; if the true depositional succession were known the culture sequences might be firmly established, but both are often in doubt. Moreover, what is really at issue is the 'internal' chronology of the main culture stages, i.e. the evolutionary progression of implements within the same general tradition. Such typological series rest upon subjective judgments based upon evidence often fragile

and always disputable. It is impossible to overlook the bewilderingly rapid changes of opinion during the last thirty years on these questions. Accordingly, geologists and geomorphologists have been wont to adopt the attitude of Gallio who 'cared for none of these things', believing that what Palaeolithic typology offered them was not a highroad but a quagmire.* Yet it seems improbable that any reliable chronology can be developed without such evidence and the comparative stability of present opinion has encouraged renewed attempts to decipher the record.

The sequence of events in the Lower Thames valley as deduced by King and Oakley[63] in the light of palaeontological and archæological evidence is as follows. The earliest deposits of the Boyn Hill terrace (the 'Lower Gravels' at Swanscombe) were accumulated following a phase of planation which formed the rock 'floor' on which they rest at about 70 feet O.D. The included fossils indicate a temperate climate. There then ensued a negative change of base-level and the erosion of a deep channel of which the floor stands at 20 feet O.D. near Swanscombe and below sea-level at Clacton. In the following phase the channel was filled as sea-level rose and the deposits finally extended beyond its lip so as to rest upon the Lower Gravel at Swanscombe. At this time, therefore, the flood-plain rose higher than in the early Boyn Hill phase and the equivalent sea-level is estimated to have stood at about 100 feet O.D. It is particularly to be noted that the acceptance of this pronounced phase of aggradation implies that lower-lying deposits may be older than those at higher levels. Thus gravels and brickearths at Ilford and Stoke Newington which occur at what would normally be considered the 'Taplow' level are, in fact, assigned to a stage of the Boyn Hill aggradation.

The great oscillation of sea-level, as deduced by King and Oakley, involving the cutting and subsequent filling of a deep channel, indicates the pattern of later events. The succeeding fall of base-level led to a renewed deepening of the valley to below its present floor, uncovering the Boyn Hill ledge with its composite covering of deposits, as a terrace, but locally sparing the lower part of the infilling of the former channel. Upon both these sets of deposits is found superimposed a well-marked layer of Chalky sludge (Coombe Rock), the product of solifluxion in a climate of glacial severity. Further down-cutting followed, in which parts of the sludge-sheet were removed; the succeeding aggradation built up the thick gravel of the Taplow stage by the end of which sea-level is estimated to have reached about 60 feet O.D. There followed a widespread phase of brickearth formation reflecting a steppe climate in which wind-blown dust was accumulated as loess or arrested by marshes or standing water to give water-laid loams.

Three further phases of down-cutting followed by aggradation are evidenced in the succeeding deposits. First was formed the rock-floor of the Upper Flood Plain Terrace: the lower part of the deposits which rest upon it yield clear fossil evidence of an Arctic climate and are associated locally with solifluxion gravels which mark the return of 'periglacial' conditions. The ensuing fall of sea-level led to the cutting of another deep channel with its floor in places as much as 100 feet below O.D. During the cutting of this gorge it is believed that solifluxion gravels continued to descend the valley slopes, but with the return of a warmer climate and a rising sea-level, aggradation was resumed and the channel was filled with gravel to a height above that of the existing alluvial flood-plain. The upper

* Thus some authorities place the Abbevillian in the second, not the first, inter-glacial period and thus relegate the greater part of the Acheulian to the third inter-glacial stage. A decision between these alternatives is evidently of prime importance in the Thames valley.

surface of the 'fill', where this protrudes above the alluvium, constitutes the Lower Flood Plain Terrace. The alluvium itself attains locally a thickness of 50 feet, and this has been taken to imply the cutting of still another channel in the earlier gravel 'fill' and its subsequent filling by aggradation.

A similar sequence of events is deduced, by King and Oakley,[63] in the Middle Thames region. The Boyn Hill aggradation is represented as filling an earlier valley and covering earlier benches excavated on its flanks. The top-most gravel of this stage is regarded as reaching a height of 130 feet above the river. The succeeding phase of erosion lowered the valley floor to about 45 feet above the present river. Aggradation followed, evidenced by gravels near Iver and West Drayton, which reach a level about 95 feet above the river. The aggradation then gave place to erosion with lowering of the valley floor to 20 feet above present river-level. There then ensued a major phase of solifluxion regarded as equivalent to the chief Coombe Rock stage of the Lower Thames. This was followed by the building up of the Taplow gravels and a phase of brickearth formation, as in the Lower Thames.

If this reading of the facts is right, the Lynch Hill Terrace surface is cut across the deposits of both the earlier (or Boyn Hill) and the later (or Iver) aggradations. It is not the upper or terminal surface of one filling but a plain of lateral river planation cut in earlier fill.

Though the details of the synthesis offered by King and Oakley are certainly open to question and will no doubt be clarified or modified by further discoveries, it is important to note that the general character of the record they deduce is entirely consistent with our growing knowledge of Pleistocene sea-level oscillations. Further it successfully recognizes and places in the succession at least two cold phases later than the Chalky Boulder Clay, which though unrepresented locally by the products of land-ice, may well correspond with true glaciation in other areas. The record thus begins to fall into line with that established for western Europe as a whole.

It is important to note, however, that the cycle of degradation and aggradation is necessarily confined to the lower or seaward course of rivers. The aggradation chiefly affects the estuaries created in previous submergence, though it might proceed for a limited distance upstream of their head. The degradation, following each depression of sea-level, would slowly work back from the mouth by headward erosion. It by no means follows, therefore, that the middle and upper reaches of a river will show a terrace record comparable with that of the recurrently 'estuarine' lower course. It has, indeed, been plausibly claimed that, in the case of a river draining directly from a glaciated area, down-cutting at the mouth, in accordance with the low sea-level, will be accompanied by deposition upstream where the river, impoverished in flow by the severity of the climate, is unable to handle the large bulk of outwash delivered to it. Conversely, in an inter-glacial or high sea-level phase, aggradation in the lower course will be accompanied by down-cutting by the now re-invigorated river in its upper reaches.

The difficulties introduced by complications such as this in correlating terraces throughout a major valley will be readily apparent. They lead to a conclusion increasingly acceptable both to geomorphologists and to students of Pleistocene stratigraphy, that terrace classification and nomenclature must stand independently of the age of the constituent gravels. For such a view there are compelling arguments. In the first place it is only the terraces which can be mapped by the

customary methods of geological survey; they are morphological and lithological units. It is clearly desirable that they should be so mapped, since they are features of direct geographical and economic significance.* Regarded as registers of denudation chronology, however, their interpretation is more difficult. The ledge-like surfaces which they present may reflect benches cut in 'solid' rocks upon which later deposits of more than one age may be lodged. Alternatively, the terrace surface may represent lateral river planation in pre-existing drift or 'solid' materials, or still again, particularly in the lower reaches of a river, the upper or terminal surface of an episode of aggradation. It is nevertheless quite apparent that the existence of a series of recognizable and traceable terraces clearly implies that, on balance, down-cutting has exceeded aggradation. There is, indeed, little doubt that the glacial oscillations of sea-level have been superimposed on a general fall of mean sea-level. This is indicated, for instance, by the fact that, even if the existing ice-masses were melted, the resulting rise of sea-level would leave the oldest known Pleistocene shore-line high above the sea.† But it is none the less clearly indicated by the consistent series of terrace levels traceable not only in the Thames but in a large number of the major rivers of the world. In the analysis of landscape evolution the important episodes and those for which the evidence is least readily obliterated are the major pauses in 'uplift', which have availed for appreciable lateral river planation. Despite the complications of aggradation phases the terrace record, in fact, remains the natural complement and continuation of that of the pre-Pleistocene benches or platforms. Together they summarize the 'uplift history', but the concordance of the record over very wide areas leaves no doubt at all that world-wide depression of sea-level is the probable cause of the apparent 'uplift'.

The force of these considerations is confirmed if we trace the relation and distribution of the three main terraces of the Lower Thames as shown in Fig. 30. In the west the central feature of the map is the broad expanse of the Taplow Terrace in South-West Middlesex. It probably included a representative of the Lynch Hill Terrace not yet separately distinguished. Down-stream the Taplow belt is narrower but developed on both banks, on the south between Richmond and Clapham and on the north, with one conspicuous break near Shepherd's Bush, as far east as the Lea at Lower Clapton. Throughout this stretch the Boyn Hill Terrace exists only in scattered remnants. On the north we have only the small outlier west of Hanger Hill, Ealing, perhaps referable to the Brent; and the larger masses at Islington and Highbury. On the south the remnants of the terrace are more continuous from Richmond to Lewisham, expanding in the large mass at Wandsworth which evidently includes part of the corresponding Wandle terrace.

* The character of the deposits themselves is increasingly important in days when gravel has become an important source of concrete aggregates; the difference between well-washed and 'solifluxion' gravels is here material and might be reflected also in detailed soil survey. The lay-out of roads and fields, however, and the siting of farms and villages is closely related to the form and distribution of terraces as such and their recognition is hence an essential element in geographical analysis.

† Zeuner[64] has estimated that the general depression of sea-level has amounted to some 70 metres (230 feet) during the last 600,000 years, i.e. about one-tenth millimetre annually. He arrives at this result by plotting present sea-level and the heights of the known Pleistocene shore-lines in relation to the absolute dates and durations of the glacial and inter-glacial periods as deduced from the Milankovitch 'radiation curve'. Without discussing further the assumptions of this method we may note that the figure is evidently of the right order, if we accept 50 metres as the 'water equivalent' of the existing ice masses. This would leave the highest (Sicilian) shore-line, dated by Zeuner at 660,000 years, about 50 metres above the 'restored' sea-level.

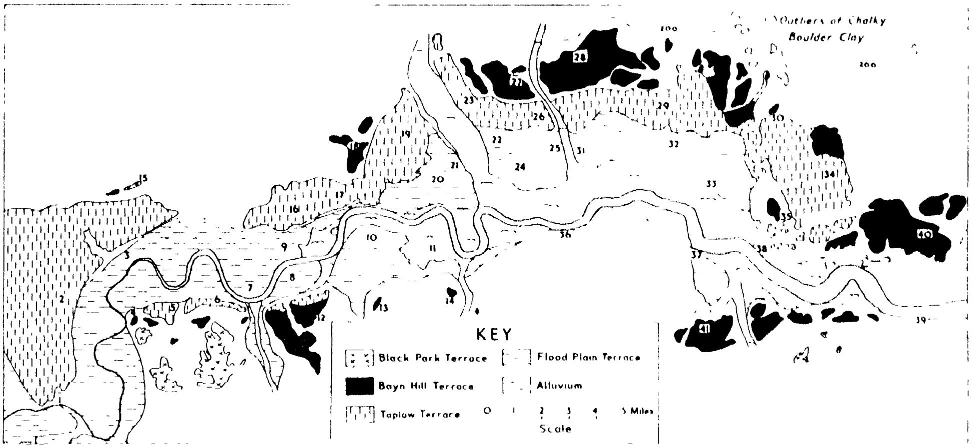


FIG. 30 – The Terraces of the Lower Thames Valley.

Numbers have reference as follows:

1 Hampton	11 Rotherhithe	21 Old Ford	31 Barking
2 Twickenham	12 Clapham Common	22 Stratford	32 Dagenham
3 Brentford	13 Herne Hill	23 Leyton	33 Rainham
4 Richmond	14 Brockley	24 Plaistow	34 South Ockendon
5 East Sheen	15 Hanger Hill	25 East Ham	35 Aveley
6 Putney	16 Hyde Park	26 Wanstead Flats	36 Woolwich
7 Fulham	17 Holborn	27 Wanstead	37 Erith
8 Battersea	18 Highbury	28 Barking Side	38 Purfleet
9 Chelsea	19 Hackney	29 Becontree Heath	39 Gravesend
10 Southwark	20 Bethnal Green	30 Upminster	40 Chadwell

41 Dartford Heath

Below the Lea confluence the terraces are more impressively displayed and the structure of the underlying rocks also considerably affects the form of the valley. The southern limit of the valley is formed by the edge of the plateau of the Blackheath Beds – a river-cliff – from Greenwich eastwards to Erith. A narrow development of the Flood Plain Terrace comes on at its foot at Greenwich, but at Charlton and again east of Woolwich, alluvium adjoins the foot of the slope. The higher terraces are completely missing. At Erith the edge of the high ground retires from the river, leaving the small triangular plain floored by alluvium and Flood Plain Gravel on which the Darent and its tributary, the Cray, debouch. Though deposits referable to the Taplow stage are known at Crayford no equivalent terrace feature is traceable. Behind the plain, from Dartford Heath eastwards to Swanscombe, the Boyn Hill Terrace is seen in one of its best known developments; it is continuous, apart from the interruption of minor tributary valleys, for a distance of seven miles and it has been well exposed in large gravel pits for more than a century. East of the Darent the gravel deposits rest largely on the Chalk which advances to the river bank at Gravesend.

On the Essex bank, the terraces are displayed in full succession. In the west the Boyn Hill Terrace is developed at Wanstead, separated by a bluff exposing London Clay from the Taplow surface at Wanstead Flats. This gives place near the line of the Romford Road to the wide spread of Flood Plain Gravel on which West Ham and East Ham stand. All three terraces continue clearly developed east of the Roding forming a gravel belt which runs in a sweeping curve first eastwards and then southwards to Purfleet and Grays. The surface of the Boyn Hill deposits is well seen around Barkingside and Fairlop Plain; this is the largest undissected mass of the terrace in the London district, but it should be noted that

its forward edge, as mapped, descends well below the 100-foot contour and may well include a development of the Lynch Hill Terrace. Continuity is broken near Romford but the terrace is well seen around Hornchurch and Upminster where it makes its contact with the Chalky Boulder Clay. Beyond Upminster the junction with the Taplow Terrace is concealed beneath brickearth and the back of the terrace has been cut away in the development of the tributary Mar Dyke valley. It is widely developed between West Thurrock and Orsett resting upon the lower Tertiary sands and it also caps what is evidently a meander-core of the Taplow stage at Windmill Hill, Aveley.

The lower terraces conform to the same pattern, the Taplow surface ranging from Ilford, past Becontree Heath to South Ockendon and Aveley, while the Flood Plain terrace forms the flat on which Barking, Dagenham and Rainham stand. It is important to notice that here the tributary valleys everywhere cut into the underlying London Clay, so that the terrace surface must represent the Upper Flood Plain feature. Above the Lea confluence the separation of this feature from the 'fill' of the Buried Channel cannot readily be made, but in Essex the latter must lie largely beneath the alluvium which forms a continuous marshland strip between Barking and Rainham.

At Purfleet the Thames crosses the nose of the Purfleet anticline and for some miles down-stream the valley is of relatively narrow and constricted form, sunk below the high plateaux of the Boyn Hill Terrace and margined by alluvium and low-level gravels except where, as at Greenhithe and Gravesend, the river cuts directly into the Chalk. Swinging northward in the Lower Hope Reach towards the outer estuary, wide tracts of alluvial marshland are developed on both banks and there is a wide gap in this terrace record. Outliers of gravel at about the Taplow level occur on the Essex bank between Stanford-le-Hope and Fobbing; it seems clear that at the Taplow, as probably also in the Boyn Hill stage, the Thames followed a course south of the Laindon Hills (p. 132).

Eastwards there are two outlying gravel areas which call for brief comment. In the peninsula of the Hundred of Hoo, separating the Thames estuary from that of the Medway, the Geological Survey has recently mapped four terraces. They have abandoned here the nomenclature used in the London area distinguishing simply First, Second, Third and Fourth terraces in ascending order above the alluvium. Judged simply on altitude and spacing the first three terraces might no doubt be regarded as the equivalent of the three main terraces of the Thames, but any such correlation must be regarded at present with caution. The Fourth terrace lies at about 150 feet O.D., with its surface rising to 170 feet in places, while near High Halstow there are small unclassified tracts of gravel at about 200 feet O.D. The terraces form a flight descending south-eastwards towards the Medway and can probably be regarded as the product of that river. Great interest evidently attaches to the higher gravels of the series for their presence raises the question of their relation to the stages of the Thames and to the contemporary marine base-level.

This group of gravels finds its analogue and perhaps, in part, its continuation in the wide gravel plain of the Southend district east of the Rayleigh Hills. On the summits of these hills, between 200–250 feet O.D., lie outliers of coarse current-bedded gravels rich in Lower Greensand debris. There can be little doubt that this material was carried by an ancestor of the Medway and that the gravels are, in fact, Medway gravels. At lower levels, between Leigh, Rochford and Shoebury-

ness, gravels occur over a considerable range of height. They are masked in great part by a wide sheet of brickearth. Judged by altitude it would appear that both the Flood Plain and Taplow stages are represented, the latter showing surface levels of about 80 feet north of Southend, but to the west gravels also occur at and above the 100-foot level, their surface rising locally to 150 feet. It seems reasonable to attribute the gravels to the Thames which appears here to have turned northwards. The gravel train is continued northwards along the coast past Paglesham, Southminster and Tillingham to Bradwell-juxta-Mare; but in this stretch the gravels nowhere attain a height of 100 feet, the greater part lying at about 70–80 feet and falling northwards.

Taken as a whole the Southend gravels appear to indicate a terrace flight falling eastwards from above 100 feet to 'Flood Plain' level. The evidence of steady easterly shift is significant and recalls the similar disposition of the Medway terraces in the Hundred of Hoo. A further analogy is offered by the gravels of the Kentish Stour, north of Canterbury. In an earlier study[65] it was concluded that these formed a flight falling eastwards and formed at a time when the Stour pursued a more directly northerly course towards the Kent coast than it does to-day. Recent work by Miss A. Coleman[66] has confirmed and extended this conclusion. She has distinguished and mapped a series of erosion surfaces in the London Clay area north of Canterbury, and these are regarded as essentially terraces of the Stour. The full range of levels recognized down to 100 feet is as follows: 400 feet, 350 feet, 300 feet, 265 feet, 205 feet, 160 feet, 125 feet, 100 feet. The several surfaces step down in succession eastwards from the high summits of the London Clay country lying about five miles west of Canterbury. They are separated from one another by low but continuous bluffs. There is a certain difficulty in interpreting the features as normal terraces since only those at the lower levels retain any appreciable cover of gravel. If, however, we accept these as river-cut features a steady easterly shift of the river is indicated and Miss Coleman invokes a slight tilting movement towards the east to explain this effect. It will be seen that the general sequence of stages is comparable, though not identical, with that traceable in the Middle Thames area, and the Hampshire Basin (p. 140). Miss Coleman enforces her argument for depression or tilting in this region by pointing out that the several terrace stages are slightly lower than their presumed equivalents elsewhere. This argument is suggestive but it probably puts more weight on the precise altimetric correlation of terraces than it can properly carry. Such a comparison can only be valid 'at base-level', i.e. on or near the line of the contemporary coasts. We do not know where the Stour joined the sea at the several stages of the series and in the case of the higher stages it was probably far to the north of the present Kent coast. Nevertheless, there is certainly a convergence of evidence in favour of a slight easterly tilting in the area about the mouth of the Thames and it is highly important to scrutinize all indications of its nature and date.

CHAPTER X

THE THAMES IN ESSEX AND ITS FORMER GRADIENTS

The discussion of the two preceding chapters evidently leaves unresolved some important questions concerning the development of the Lower Thames drainage system, and to these we must now turn. They may be briefly summarized as follows:

1. What course was followed by the Thames of the Lower Gravel Train, east of the Lea valley and by the Thames of the Winter Hill stage east of Uxbridge?

2. What gradients can be ascribed to the river at these stages and to what marine base-levels were they graded?

These questions immediately direct our attention to the widespread drift-covered areas of central and northern Essex of which our knowledge is at present very incomplete. The questions we have posed cannot be finally answered without detailed work in this area, but it will be worth while to discuss them briefly with the hope of assisting such future work.

On general grounds it must appear very probable that the early Thames pursued a course across central Essex. This route, indeed, affords the only probable outlet to the contemporary coast before the first diversion by the Chiltern ice, but of the details of this early course we have at present no evidence. At the Lower Gravel Train stage we are on somewhat surer ground. At this time we have inferred that the drainage of the Middlesex loopway met the revived or resumed drainage along the Vale of St. Albans in the neighbourhood of Hertford. Eastwards there opens the broad trough of the lower Stort valley, and even if we confine our study to the form of the present drift-covered surface, there is a plain suggestion that the combined drainage passed eastwards through the trough towards Chelmsford and the coast. The whole area, however, is thickly drift-covered and we are at present without any adequate stratigraphical details of the drift. There has been no six-inch revision of the Epping sheet or of the country to the north and east of it and the only geological maps available are the hand-coloured sheets now nearly a century old. These indicate sufficiently well, in broad terms, the distribution of the great sheet of boulder clay, the gravels associated with and for the most part underlying it, and the later river deposits then regarded as 'post-glacial'. It cannot be doubted that much detail remains to be recorded and that a more complicated classification of the drifts would result from detailed survey. Meanwhile it is possible to obtain some evidence on the form of the sub-drift surface from well records.

In interpreting the surface so revealed there are three manifest difficulties. In the first place we cannot evaluate the direct glacial erosion. Further west, as we have noted, it would certainly seem that the ice was passive, merely occupying existing depressions. But we cannot assume that here, further from the ice margin,

no erosional activity took place; further north, near Royston,[67] the ice demonstrably disturbed large masses of Chalk. It is clear, in any case, that the deep drift-filled channels, known south of Hitchin, in the Stort-Cam valleys, and elsewhere, reflect some sort of sub-glacial action; they were probably scoured out by water beneath the ice.

Even if we discount such local effects there remains the possibility that drifts of more than one age are present within the area. The older mapping reflects the assumption that there was here one boulder clay, resting locally on sands and gravels, the 'Middle Glacial' of S. V. Wood, which in turn were younger than other drifts in the Cromer and Norwich area. In fact, however, the full East Anglian glacial sequence, as now interpreted by Solomon,[62] includes four distinct glacial phases. If, as seems probable, part, perhaps the larger part, of the Chalky Boulder Clay marks his 'Great Eastern' glaciation we are left completely in doubt as to the distribution of the ground moraine, if any, of the later 'Little Eastern' glaciation. This is represented locally by what may be little more than a solifluxion sludge, but if land-ice occupied the area at this stage its deposits have not yet been separated from the 'Great Eastern' boulder clay. East of Chelmsford, at Danbury, Tiptree and around Colchester, there are large tracts of gravel which may or may not be associated with the main sheet of boulder clay. Some of their features are suggestive of the 'Newer Drift' of more northerly areas. It is clear at least that, pending the re-survey of the area, it is altogether too simple an assumption to treat the Essex drifts as a single suite of deposits. In so far as they differ in age, the surfaces beneath will themselves be of widely different age.

Finally, we must reckon with the fact that the East Coast area has suffered tectonic warping absent throughout the greater part of South-East England. A. W. Woodland[68] has shown that the Crag deposits have been affected by post- or intra-Pliocene folding north-east of Stowmarket, and there is much other evidence to suggest an eastward tilting of the area towards the North Sea depression. Of the date and duration of such movement we have little precise indication but we certainly cannot assume that it was not in progress during Pleistocene times.

These several considerations render it quite impossible to reconstruct a simple 'sub-glacial' surface beneath the drifts hoping thereby to perceive the lineaments of a pre- or inter-glacial drainage. Until the area has been re-examined speculation soon becomes profitless. Nevertheless, there are some suggestive features in the distribution and disposition of the drifts of which we may take account.

The lower Stort valley between Roydon and Harlow is cut wholly in drift which obviously fills a wider depression trending from west-southwest to east-northeast. This is bounded on the south by the ridge (over 300 feet) of Epping Long Green; on the north boulder clay is continuous over the high ground and no clear limit to the depression can be seen in the surface contours. Well records show, however, that the floor of the main trough beneath the drift occurs at levels between about 145 feet and 170 feet. The depression broadens eastwards into the country about the upper Roding valley. Here there are records of the sub-drift floor at 145 feet O.D. at Abbess Roding and 106 feet O.D. at Berners Roding.

North-eastwards from Chelmsford the form of the floor becomes complicated and difficult to interpret. It descends well below 100 feet O.D., and even below sea-level at Witham and Kelvedon. Here, however, we are south of the main boulder clay edge and the date of the 'floor' revealed is uncertain. There may

possibly be a sub-drift channel in this neighbourhood. Alternatively, we may be dealing with the results of river erosion and aggradation of a much later date (cf. p. 122). The only fact on which we may certainly depend is that the boulder clay itself descends below 200 feet in the Chelmer and Blackwater valleys and we may define a broad depression trending north-east towards Colchester. To the south lies the high gravel mass of Danbury and the continuing ridge of Wickham Bishops and Tiptree. Along the ridge the sub-drift floor descends from 250 feet at Danbury to 185 feet at Tiptree. Northwards of the main trough the sub-drift surface climbs more slowly reaching the 200-foot level to the south of Dunmow and Braintree. In this neighbourhood large areas of the floor lie at or about 200 feet, but lower levels are recorded in the vicinity of all the main valleys. As a whole this great mid-Essex trough is evidently a continuation of the lower Stort depression but present evidence does not avail to demonstrate whether any former through drainage was eastwards towards the Stour estuary or westwards (as it is to-day) towards the Blackwater exit.

If we turn now to the margin of the glaciated area south and south-west of Chelmsford, the relations of the drift to its floor are more certainly known, for the ground has been re-surveyed on the six-inch scale.[69] Along the Roding and Wid valleys much of the boulder clay lies at about the 200-foot level, but it climbs higher, to 300 feet, or above, on the margins of drift-free ground, as at Brentwood and Billericay, and descends consistently to about 150 feet, or below, along the valley lines. It is possible to draw, with fair accuracy, the 200-foot contour of the sub-drift surface; in the Wid valley this line defines the form of a sub-drift valley draining northwards like its present successor. There is a clear suggestion that the Roding valley from near Chigwell north-eastwards is relict of a similar valley draining north-eastwards towards the mid-Essex depression before the emplacement of the drift.

The consideration of this possibility at once directs our attention to the attitude of the drift-sheet along its southern edge where it overlooks the Lower Thames valley. The relations are illustrated in Fig. 31. From Chigwell, eastwards to the neighbourhood of Billericay, the boulder clay rests on a plateau which presents a sharp southern brink to the Thames valley. Much of the drift lies at or just above 200 feet, but it climbs higher on the flanks of higher drift-free ground, as near Lambourne End and Havering, and descends below 200 feet at three places, viz. north-east of East Horndon, south of Childerditch Sheet, and in the country north of Upminster. The relations of the boulder clay near Upminster are peculiar and singularly important. At Noak Hill we find it at the 200-foot level and it caps the spur which extends thence southwards to Maylands. This spur separates the two head streams of the River Ingrebourne which flows southward to the Thames at Rainham. In both these valleys outliers of boulder clay occur below 200 feet; they are evidently the dissected relics of the drift of an ice-tongue which extended as far south as Upminster. Here, early in the century, T. V. Holmes[70] showed that the gravel of the High (or Boyn Hill) Terrace of the Thames rested upon the boulder clay at about 100 feet O.D., near Hornchurch; he later showed that a further small mass of boulder clay lay beneath these gravels south-east of Romford. Thus was established a vital fixed point in the Pleistocene stratigraphy of the Thames valley and one upon which most of the correlations since proposed have essentially rested (p. 121). It is true that we have no palaeontological proof of the age of the gravels in question; a similar contact between boulder clay and gravels was exposed

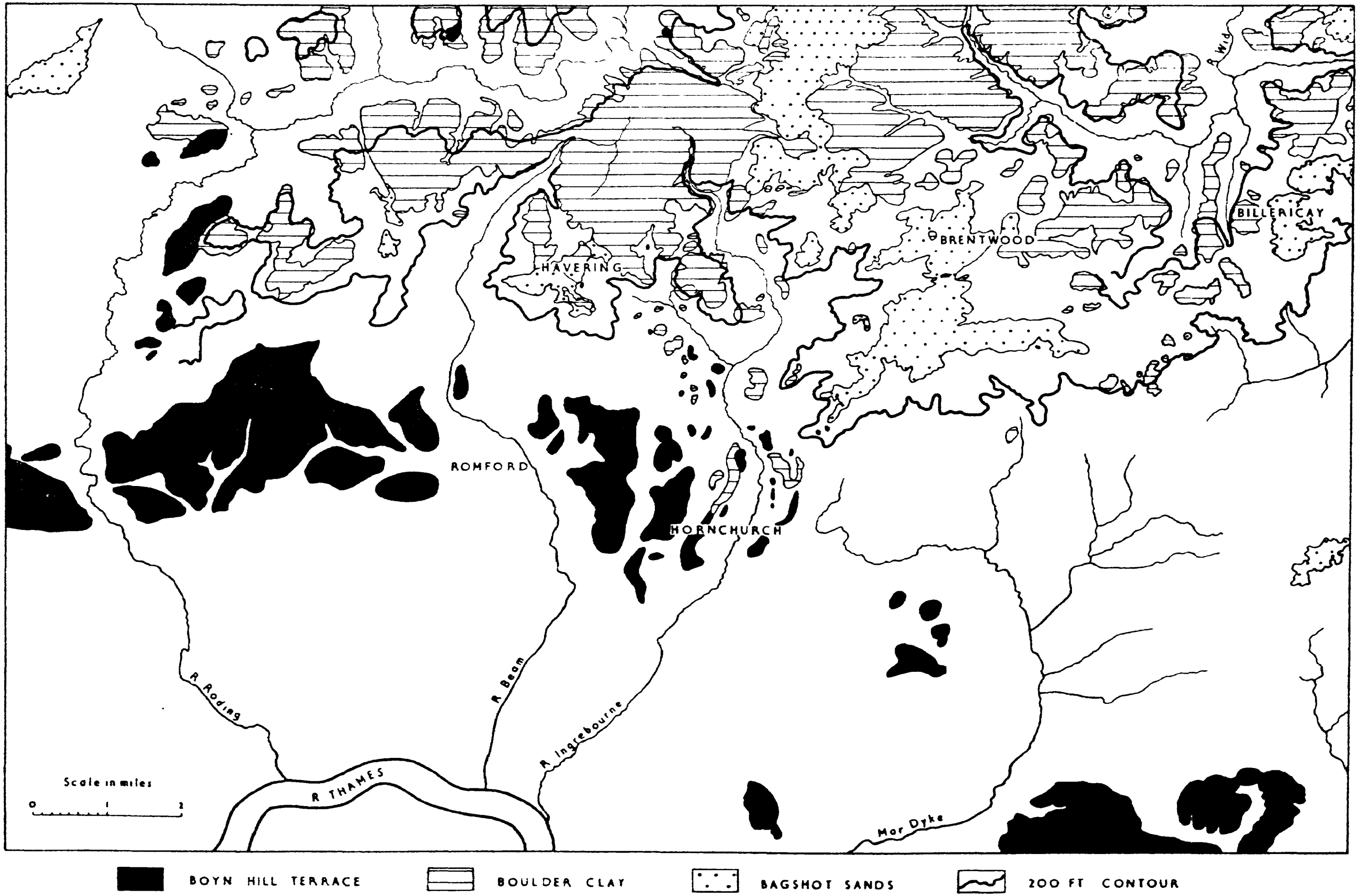


FIG. 31 – The relation of the Chalky Boulder Clay to the Boyn Hill Terrace in Essex.

in 1923 by the cutting for the new Southend Road, and it then appeared to some that the gravels might be 'glacial'. There is no reason whatever to regard this surmise as correct; even if it were true there is still the patent physiographic fact that the ice here descended into a pre-existing depression and spread its drift at about the same level as that at which the gravels of the Thames High Terrace were subsequently deposited. It is to be noted that the descent of the boulder clay in the Ingrebourne valley is entirely consonant with its relations in the Roding and Wid valleys, though it descends to a lower level. What renders the occurrence particularly notable is its isolation. About five miles to the west, the Beam River flows southwards to the Thames near Dagenham (Fig. 31). The broad re-entrant cut by its headstream in the boulder clay plateau shows no trace of low-level outcrops of boulder clay. Near Curtismill Green it has almost cut through into the Roding valley, and if it were not for the evidence provided by its neighbour, it would be natural to conclude that these steeply descending Thames tributaries had recently pushed back and dissected the plateau edge, bringing into being its steep scarp-like brink. Nor is there any reason to doubt that such processes have, indeed, been active, but the occurrence of boulder clay in the Ingrebourne valley and its presence beneath the terrace gravels at Hornchurch and Romford demonstrate the existence of an earlier trough or depression in this neighbourhood.

At first sight this might seem to show that the Lower Thames valley was itself 'pre-glacial', but there is no real warrant for such a conclusion. The depression in question is not the Thames valley, but what Holmes called the valley of the 'Romford River'. The northern limit is traceable eastwards of Billericay past Downham and South Hanningfield to Great Canney, south of Maldon. There is no modern geological map of this ground: the old hand-coloured maps show that the boulder clay continues to lie at or about 200 feet, descending only slightly below this level along the northern margin of the depression. The southern margin, though evidently now much dissected, is formed by the higher ground of the Laindon Hills and the Rayleigh Hills, continued beyond the Crouch in the Althorne ridge. Taken as a whole the depression is a flat-floored trench, three to four miles wide, trending north-east to south-west and thus aligned with the lower part of the Blackwater estuary. The floor level north of Laindon is at about 150 feet O.D. falling eastwards. The known terrace drifts of the present Thames lie wholly south and east of the broken ridge which bounds the trench on the south. Westwards, in the area shown in Fig. 31, the southern limit of the trench has not survived the later development of the Thames valley which, as it were, overlaps with or includes a portion of the earlier depression. East of Laindon this depression is, functionally, the valley of the Crouch, but it makes an angle of some 30° with the general trend of this river and shows every appearance of having had an independent origin. No final conclusions as to the manner and date of this origin can properly be sought until the ground has been re-mapped, but it is surprising that the general features and relations of the trench, early perceived by Holmes, have since received so little comment.

We may return now to the question we asked at the outset concerning the seaward course of the Thames at the stage of the Lower Gravel Train. It is clear that, considering the evidence in *plan*, there is considerable support for the hypothesis of a main drainage line across central Essex, with tributaries entering from the north and the south. The present rivers, Stort, upper Roding, Chelmer, Brain, Pant-Blackwater and Colne probably follow lines close to those of their ancestors.

On the south the Wid and Sandon Brook remain as descendants of earlier northward-flowing streams, while the lower Roding, between Chigwell and Fyfield, north of Ongar, may well mark the line of another such tributary, since reversed by capture and southward diversion to the present Lower Thames drainage. It will be noted that the eastern part of the Middlesex loopway is parallel to the central section of the Roding valley and may well have *originated* as a similar south-bank tributary of an earlier axial line of drainage even though it later served for the diverted Thames.

If we tentatively accept this basic pattern of drainage, we are still left in doubt as to whether the ultimate seaward outlet was in the neighbourhood of the present Stour or the Blackwater estuary or whether, indeed, each may not be relict of a former course of the Thames. On the whole it appears more probable that the exit at the Lower Gravel Train stage was in the vicinity of the Blackwater estuary.

We may now turn to the related question of the course of the Thames at the Winter Hill stage.

It is clear that we have no evidence of the presence of the Thames within its present valley through London before the time of the Chalky Boulder Clay glaciation. A reasonable physiographic interpretation of this fact is afforded, as we have seen, by the hypothesis that the Thames was diverted from a more northerly line by the advance of the Chalky Boulder Clay ice. Not until this diversion had been effected did the river assume possession, as it were, of its present lower valley.

This conclusion evidently commends itself on general grounds if we consider the distribution of the glacial and valley drifts as a whole. The argument is, indeed, graphically presented by the view from the summit of Hampstead Heath. Northwards, between Hampstead and the hills around Barnet, lies a broad trough with its general floor-level, ignoring later dissection, at about 200 feet. On its floor lie the glacial deposits of the Finchley district and it is clear that they are the product of a tongue of ice advancing into the depression from the north-east. Southwards lies the valley of Thames, much wider and deeper than the Finchley depression; within it lie the chief Palaeolithic deposits of the area. These on all grounds are to be regarded as younger than the Chalky Boulder Clay, but the valley in which they lie reveals no trace of glacial deposits except far downstream near Upminster.

Confirmatory evidence of the act of diversion is given by the gravels of the Wimbledon plateau. These form the surface of Wimbledon Common and Putney Heath and are represented in smaller outliers at Kingston Hill and Richmond Hill. Their surface reaches a height of 198 feet near Wimbledon, but the general level is 175–180 feet, and the thickness in places attains about 25 feet. The gravels yield abundant Triassic debris: here alone, indeed, in the Lower Thames area, 'glacial' gravels rich in Bunter quartzites cross the line of the river. Yet they lie fully within the Lower Thames valley and it is even probable that the surviving gravels mark very closely the line of the Thames itself at the time of their deposition. This is suggested by the fact that on the south of the plateau at Kingston Hill the gravel comprises mainly southern material, flint, Lower Greensand chert, ironstone, etc., together with about 10 per cent of 'northern' constituents – Bunter quartzites, igneous rocks, etc. On the northern side of the plateau, in Richmond Park, northern material forms more than half the total.

These gravels are clearly older than those of the Boyn Hill terrace which adjoins them at Richmond and Roehampton. They rest at a level below but not much below that at which the outwash from the Chalky Boulder Clay ice must have been confluent with the Winter Hill Terrace in what is now the Colne valley. Accordingly, in a first survey of the problem they were correlated with the Winter Hill Terrace and taken as confirmation that the southerly diversion of the Thames was effected at this stage.

This conclusion needs to be reviewed in the light of two newer discoveries, the recognition of the Black Park Terrace by Hare[56] and the dating of the Winter Hill Terrace, near Reading, by Arkell and Oakley.[57] Here the gravels of the terrace have yielded a large group of implements of Abbevillian and Early Acheulian culture. This is clearly a pre-Boyn Hill assemblage and is referred by those authors to the *first* inter-glacial period. If this correlation is accepted we appear to be confronted with a conflict as to whether the Winter Hill Terrace is earlier than or coeval with the second, or Chalky Boulder Clay glaciation. But, in fact, this conflict is more apparent than real. It exists only if we press either of the methods of dating to an assumed precision which it cannot support. If, as Hare strongly confirms, the outwash of the Chalky Boulder Clay ice in the Colne valley is disposed at about the level of the Winter Hill Terrace, this evidently affords no close indication of the date of the latter: it cannot well be later than the outwash, but it might evidently be earlier. All that the relation proves is that this particular mass of outwash entered the Thames valley before it had suffered any further substantial deepening *in this area.* The bearing of the problem may perhaps be more clearly seen if we imagine that glaciation was resumed at the present date. The gathering of the ice-sheet would be concurrent with a fall of sea-level and the Lower Thames would cut down its course accordingly. But until such down-cutting had reached the mouth of the Colne, any outwash descending the valley of this river would be disposed on the present floor of the Thames valley. It is conceivable that the existing flood-plain deposits might be reconstructed wholly or in part in such an episode and it is clear at least that, without palaeontological control, our successors might be quite unable to distinguish the outwash from the pre-existing deposits.

In the light of this discussion it will be clear that physiographic evidence cannot date the Winter Hill Terrace with precision. The work of Arkell and Oakley gives this terrace a new status and makes it very probable that it is, in fact, 'inter-glacial' or, at least, that deposits included in it are earlier than the Chalky Boulder Clay. If, however, we now combine the archæological and the physiographic evidence it at once appears very doubtful whether we can properly correlate the Wimbledon-Kingston gravels with the Winter Hill Terrace, for this would imply that the Thames occupied its present lower valley *before* the Chalky Boulder Clay glaciation and we should be without any plausible explanation of why it came to adopt such a course.

The recognition by Hare of the Black Park Terrace may well afford an acceptable solution to the problem. As earlier noted by Zeuner,[64] correlation of the Wimbledon gravels with the Winter Hill Terrace implied a relatively steep local descent of the terrace surface: he suggested, indeed, that the Wimbledon gravels were a separate spread which he termed the Kingston leaf. It is now quite clear that correlation with the Black Park Terrace is preferable. This correlation is consistent with the general physiographic evidence of diversion of the Thames. The Chalky Boulder Clay glaciation was undoubtedly a long and complex episode and

many details of its internal chronology are at present unknown to us. Recent work in the Vale of St. Albans suggests that there were at least two distinct advances of the ice separated by a recession, and two corresponding marginal diversions of the local drainage. This alone is sufficient to qualify the over-simple picture of a single rapid advance of the ice which produced, as it were, an instantaneous diversion of the Thames. The full circumstances of the diversion cannot, in the nature of the case, be known. Correlation of the Wimbledon gravels with the Black Park Terrace is equivalent to stating that the diverted route via the Lower Thames valley was established *by this date.*

It may well seem that the foregoing discussion is rather academic, in that the isolated situation of the Wimbledon plateau precludes a definitive conclusion and that, if our diversion hypothesis appears generally reasonable, its precise date is unlikely to be ascertainable and in any event is of relatively little moment. But, in fact, the correlation has important implications if we enquire as to the downstream course of the Winter Hill terrace. It is, of course, possible to assume that it passed down the Lower Thames valley, but has since been completely destroyed. This is an unsatisfactory hypothesis since there is no means of testing it. It appears equally probable that it followed the line of the Middlesex loopway like its predecessor, the Lower Gravel Train. A possible course can be reconstructed eastwards from Uxbridge passing south of Harrow Hill and so into the Finchley depression. Throughout this course and onwards past Southgate to Enfield there are gravels lying near 200 feet. They might, it is true, be dismissed as glacial outwash, but it is important to notice that over wide areas in Essex the boulder clay rests directly on the London Clay. The only important areas, indeed, in which it rests on gravels are the Vale of St. Albans, the mid-Essex depression and the equivalent trough in Middlesex in which we are now considering. In general, however, we have no decisive petrographic criteria by which we can discriminate pre-existing river gravels from true outwash. In fact, the gravels of the Finchley-Southgate area are of very simple constitution. They are nowhere well-exposed at present but have been seen in former sections which revealed little evidence tending to link them directly with the boulder clay.* Their characters are, indeed, wholly consonant with origin as normal river gravels. If we adopt the hypothesis that the Thames followed the Middlesex loopway route at the Winter Hill stage, its corollary is that gravels of both this and the preceding stage formerly occupied the floor of the valley. Since such gravels, if they existed, were, in fact, overrun by the Chalky Boulder Clay and subject therefore to an unknown measure of disturbance or reconstruction, we can hardly hope to find the two stages still clearly preserved. It is worthy of note, however, that the range of height of the surviving gravels is at least consistent with our hypothesis. Thus the gravel plateau, extending from Cockfosters to Southgate, falls in level southward from well above 300 feet to about 200 feet. The highest parts of the gravel sheet are admittedly too high to form part of our Lower Gravel Train, but the lower parts might well represent the continuation of the Winter Hill level, for which we can

* The presence of Bunter quartzites is evidently indecisive since they occur equally in the western river gravels and the outwash gravels. We may here recall an observation of George Barrow's that the boulder clay is full of broken flint nodules which are rare or absent in the gravel on which it rests. They led Barrow[48] to suggest that the gravels were often pre-existing deposits insulated from the advancing ice by a surface layer of compacted snow. His suggestion concerned the Hertfordshire drifts, but it may well be applicable in the case of the North London gravels, especially to those around Finchley and Southgate.

also find possible equivalents along the western side of the Lea valley from Enfield northwards to Broxbourne.

These considerations at once bring us to the second problem noted above, that of the longitudinal gradients of the gravel trains. If we accept the correlation of the Winter Hill Terrace with the First Inter-glacial period, we may frame a tentative hypothesis on theoretical grounds. The Winter Hill Terrace should correspond with a high sea-level and show a small gradient in its seaward parts. The rather older Lower Gravel Train might be expected to show a steeper gradient if, as is likely, it was formed during or shortly after the First (Chiltern) glaciation. Similarly the Black Park Terrace should fall *within the interval of low sea-level* corresponding to the Chalky Boulder Clay glaciation and accordingly show a relatively steep gradient.

These deductions could, of course, claim little force without supporting field evidence, but, in fact, they can be matched already to some extent with observations. In the ground carefully mapped by Hare, the surface of the Lower Gravel Train shows an average downstream gradient of about 4 feet per mile and the corresponding figure for the Black Park Terrace is about 2½ feet a mile. By comparison, the surface of the Winter Hill terrace is very gently inclined, at a gradient not exceeding 1 foot per mile. So far, therefore, the facts fit our deduction in significant degree. It must be noted, however, that our gradients are measured in an area in which the three terrace surfaces are fairly continuous. Any attempt to project them downstream is speculative in the extreme; the gravel surfaces are discontinuous and we cannot simply project linear gradients at the above rates over distances of 30–40 miles. Nevertheless, it is worth noting that, if such gradients were maintained, the surface of the Lower Gravel Train, assumed as passing along the Middlesex loopway, would fall to about 170 feet near Broxbourne, while the Winter Hill level at the same point should be at about 200–220 feet. The first estimate has little significance; we do not know the position of the coastline at this stage and have no means of computing the probable flattening of gradient downstream. The error in the second estimate is almost certainly less, and a certain amount of independent evidence can be adduced in support of the conclusion that the Winter Hill Terrace was graded to a sea-level at about this height.

This evidence takes the form of widespread plateau remnants in parts of our region at about 200 feet above sea-level. These are, indeed, so numerous and widespread that they were grouped in an earlier study as the '200-foot platform', regarded as marking a major stage in the denudation chronology of the area. This conclusion can still be sustained if due regard is paid to the extent of the area to which the term is applicable and to the relation of the planation to the valleys of the time. It is evident, for instance, that no 200-foot platform can be recognized in the Middle Thames region for both the higher Gravel Trains and the better marked terraces at lower levels have a strong downstream gradient; it is probable that the surface of the Boyn Hill Terrace itself is close to 200 feet O.D. in the neighbourhood of Reading. Immediately west of the Colne, however, the ground between 200–250 feet appertains to the Winter Hill and Black Park stages and though the details have yet to be studied there is no doubt that one or both of these stages is recognizable in the valleys of the Bagshot country.

East of the Colne we have the significant fact that the sub-drift floor of the lower parts of both the Finchley depression and the Vale of St. Albans is close to 200 feet O.D., though there are few well marked remains of a similar level in the Thames valley itself. Where we cross the Lea into Essex we have the clearest

evidence that much of the Chalky Boulder Clay lies at the 200-foot level. On this fact important correlations have been based by some and these may, in fact, be justified. It is essential to emphasize, however, two manifest facts about the sub-drift surface in Essex. In the first place, as we have seen, there is widespread and consistent evidence that the rivers were definitely incised within any 200-foot platform before the advance of the Chalky Boulder Clay ice. The phase of planation therefore is substantially older than the glaciation. The rivers evidently responded to a falling sea-level with the first onset of glaciation and headward erosion from the contemporary coast was able to proceed at least as far west as western Essex. There are, in fact, some low-lying outcrops of boulder clay even west of the Lea valley, near Wormley, which may well mark the head of the 'cut-backs' which preceded or accompanied the spread of the Chalky Boulder Clay ice.

Secondly, we must notice that if we draw a line north by east from the Lower Hope Reach of the Thames, through Braintree to the neighbourhood of Halstead, there is only one record east of the line (viz. at Danbury) which shows the sub-drift surface at or above 200 feet. It seems very probable that this line marks roughly the 'hinge' or western limit of warping towards the North Sea Basin. It is certain at least that no evidence can be adduced at present for a '200-foot platform' east of the line and when we recall the probable attitude of the Pliocene base in this area and the suggestive indication of easterly warping shown by the terrace levels about the mouth of the Thames, the general tenor of the evidence in favour of an easterly tilting can hardly be questioned.

A review of these facts permits the surmise that the drainage of the Winter Hill stage was graded to a sea-level at about 200 feet, but decisive evidence is still far to seek. The sea-level of the Boyn Hill aggradation at about 100 feet, probably represented by the Goodwood raised beach of the Sussex coast (p. 142) has been taken by Zeuner[64] and others as the equivalent of the 30-metre or Tyrrhenian sea-level of the Mediterranean series. In this type area its predecessor is the 60-metre of Milazzian raised beach: its British equivalents, if any, are to be looked for at the stage of the First Inter-glacial period. It is permissible therefore to point out the evidence that the Winter Hill terrace may well have been graded to a 'high sea-level' at about this height, but it is essential to recognize that anything amounting to proof is not at present at hand. It is possible that at the eastern end of the Middlesex loopway we are not far from a 'Milazzian' coastline, if any, but the greater part of any such coastline, if preserved at all, lies buried beneath the Essex drifts. At least it would be very discontinuous in view of the magnitude of the succeeding pre-Chalky Boulder Clay erosion, and in eastern Essex and throughout East Anglia, any equivalent feature, or contemporary off-shore deposits, must evidently lie well below the supposed 'Milazzian' level.

No satisfactory downstream correlation for the Black Park Terrace has yet been established. Zeuner thought that his 'Kingston leaf' might be represented by part of the gravels at Dartford Heath, mapped by the Geological Survey as Boyn Hill Terrace, but reaching a surface level as high as 130 feet. On the opposite side of the Thames valley there are gravels south-east of Great Warley Street, mapped as glacial and with their surface at about 150 feet. These might conceivably mark a downstream continuation of the Wimbeldon gravels, but the suggestion is no better than surmise. If we adopt it as a working hypothesis, we note that these gravels lie within the valley of the 'Romford River' of T. V. Holmes (p. 132) and it is tempting to speculate on the possibility that this feature marks the

seaward course of the Thames at the Black Park stage. It is clear that the original floor of the trench cannot have been lower than 150 feet O.D. north of Laindon; we cannot safely project its gradient further east, since we at once enter the area probably subject to down-warping.

If this reconstruction is tentatively accepted it appears likely that, after a period of further slight down-cutting, the Thames was diverted to its present line by the advance of the ice into the valley at Romford and Hornchurch. This would mark the latest of the series of glacial diversions we have traced, and would be consistent with the evidence of other areas (p. 135) which suggests two distinct periods of advance of the Chalky Boulder Clay ice. Taking the evidence as a whole there is a strong suggestion, as earlier noted by Zeuner,[64] of the successive falls of sea-level during this glaciation to which the river adjusted itself. The details must remain obscure until the Essex drifts have been re-mapped. A measure of our present ignorance of the area is given by the fact that the strong down-cutting responsible for the Clacton channel of King and Oakley appears on present evidence to be later than the glaciation and, so far as is known, it is not associated with any evidence of a contemporary cold climate.

CHAPTER XI

THE DENUDATION-CHRONOLOGY OF THE EXTRA-GLACIAL AREAS

The discussion of the last chapter has to some extent broken the thread of the general story of denudation-chronology we are seeking to trace. It is necessary in our treatment of the region as a whole since, in the first place, we must obviously attempt to relate the sequence of glaciation to that of the growth of the valleys and this cannot be satisfactorily done without tracing the valleys to the sea.

We may turn now to the areas south of the Thames which were immune from the activity of land ice. Here we shall find that in some respects the record is clearer; it confirms the sequence we have traced in several vital particulars and to some extent supplements it. We may conveniently treat the area in its two natural divisions of the Weald and the Hampshire Basin, including with the latter the contiguous tracts of the Wessex Chalk.

The Hampshire Basin

In its broad features the drainage of the Hampshire Basin evidently repeats that of the London Basin, if allowance is made for the act of submergence which separated the Isle of Wight from the mainland. Nearly a century ago the Rev. W. Fox,[71] curate of Brixton, recognized that the Solent was the submerged continuation of the Dorset Frome and this conclusion has been confirmed and elaborated by later workers. This 'Solent River' was the axial stream of the synclinal basin, analogous to the Thames; the southward flowing rivers from the Dorset Piddle to the Hampshire Meon, and some at least of the Sussex rivers, were its north bank tributaries, while the northward flowing streams of the Isle of Wight and Purbeck are all that survive of a family of southern tributaries. Here there has been no modification by glacial diversion. The earliest ancestor of the Solent River may have been brought into existence by the Mid-Tertiary folding. If so, its descendant must have resumed much the same line when the Pliocene sea-floor emerged, and this was maintained, subject only to uniclinal shifting and minor lateral wandering, during the greater part of the post-Pliocene cycle. The submergence of the lower course of the Solent River combined with the marine in-break which formed Christchurch Bay has since dismembered the system.

The maps of the Geological Survey, which are complete for the area, at once reveal an extensive series of plateau and valley gravels recalling those of the London Basin. The maps are initially misleading in that gravels within the normal terrace range, i.e. broadly equivalent to those of the Boyn Hill and Taplow Terraces of the Thames, are included in the 'plateau' category. It is characteristic of the area that the main valley floors are bounded by high and continuous bluffs. The ground was mapped before any generally applicable classification of river terraces had been devised and accordingly all the gravels above these bluffs were treated as plateau gravels, leaving only the lower terraces and the flood-plain deposits within

the valley gravel group. It has long been known that a true terrace sequence is traceable in the lower 'plateau gravels'. The elements of such a sequence were clearly recognized and mapped by Clement Reid[72] on the Ringwood sheet, and the Bournemouth plateau gravels have been the subject of notable studies by Henry Bury[73] and more recently by J. F. N. Green.[74]

The general disposition of the gravels is very similar to that seen in the London Basin. They range in height from about 400 feet, on the higher New Forest summits, to the valley bottoms. If we seek for equivalents of what we have termed the Stage II drifts of the London Basin we find them chiefly in the north-western part of the New Forest where narrow ridges radiate westward and southwards from a culminating point lying some six miles east of Fordingbridge. Only small areas of this dissected plateau exceed 400 feet in elevation, and there the gravels contain large rounded cobbles which were attributed by Bury to marine action. It is difficult to recognize clearly-marked terrace stages in the summit gravels below this level. If we trace the main ridge south-westward towards Ringwood from Black Bush Plain on the Southampton-Salisbury Road, successive spot-levels, for the most part at intervals not exceeding half a mile, are at the following heights: 419, 409, 391, 392, 375, 362, 352, 347, 341, 336, 319, 313, 312. There is thus little evidence of local flattening in the crest profile and the ridge is, in fact, so narrow that it is unlikely that original levels are preserved. The end of the ridge certainly flattens, however, below 330 feet and the same is true of the more northerly spurs of the plateau which descend towards the Avon valley between Ringwood and Fordingbridge. In these flats Bury saw evidence of a terrace which he was disposed to correlate with the highest or 'Sicilian' stage of the Pleistocene marine levels of the Mediterranean, at about 100 metres.

Below this level eight distinct terraces can be distinguished, if we include the flood-plain gravels as the lowest member. They have been traced by K. R. Sealy, in hitherto unpublished work, in the valleys of the Avon and the Test. His results are summarized in the following Table, which gives for each terrace the range of surface elevation between Ringwood and Bournemouth in the Avon valley and between Romsey and Southampton in the Test valley:

	Avon	*Test*	*Solent*
VIII	240–232	275–268	230
VII	225–205	210–200	185
VI	197–155	180–170	165
V	140–122	134–115	110
IV	124–100	122– 98	85
III	120– 72	80– 70	50
II	78– 42	44– 38	—
I (Flood Plain Gravels)	68– 35	– 25	2

We are concerned also with the terraces of the Solent River itself which are strongly developed in the Bournemouth and New Forest areas. In the former area they have been studied by J. F. N. Green, and more recently C. E. Everard of the University of Southampton has carried the work eastwards. The surface levels of the Solent terraces recognized by him are stated in our Table: in comparing them with Sealy's figures for the Avon and Test terraces it should be noted that Everard has quoted a level as far east, i.e. as near base-level, as possible along the course of the Solent River. If due allowance is made for this fact the agreement in the results of these two investigations, conducted quite independently, is very satisfactory.

Certain possible discrepancies are evident but they are not considerable when we consider the difficulties of precise morphometric study of terraces, some of which have suffered the rigours of Pleistocene climate, and the resulting mass-movement, during a period of perhaps a million years. We may note, moreover, that the results achieved are essentially accordant with those of J. F. N. Green, representing, indeed, a direct extension of his own work and methods. Green gave names to the terraces;* we shall not use them here, since they imply more than can at present be strictly proved, in terms of long distance correlation. We may note, nevertheless, that terraces III–VIII fall closely into line with those of the Middle Thames valley as defined by Hare.

Perhaps the most significant feature in the sequence of the Hampshire terraces is the large vertical interval between terraces VI and V.† There is considerable archæological evidence in favour of Green's correlation of terrace V with the Boyn Hill Terrace.[75] If we adopt this view, the major phase of down-cutting in question would seem to represent the fall in sea-level concurrent with the early stages of the Chalky Boulder Clay glaciation. It is marked on the ground by a continuous bluff with its base at about 145–150 feet which may be traced across the southern part of the New Forest area. This was regarded by Clement Reid as a marine cliff, though later workers seem agreed that the gravels at its foot are essentially river gravels. It is notable, however, that neither terrace V nor its two lower successors (IV and III) show any appreciable downstream gradient between Christchurch Bay and Southampton Water. Each terrace here shows what Green termed a 'horizontal segment' and the more recent careful measurements of Everard have confirmed this important fact. We may reasonably conclude that the gravels in question were accumulated in a succession of tidal estuaries not far from the contemporary coast.

Taking the Solent terraces as a whole they present an impressive and concordant series. They are perhaps best seen in the country around New Milton. In a six-mile traverse from Burley Hill to Milton we descend a nearly full sequence of the terraces with their surfaces at the following approximate elevations: VII, 210 feet; VI, 180 feet; V, 140 feet; IV, 90 feet; III, 70 feet. The succession of the terraces suggests a course of steady uniclinal shifting such as we have traced in the Middle Thames valley. At higher levels there is evidence of terrace VIII and of stages at about 330 feet and 400 feet. Everard also seeks to distinguish stages at 285 feet and 390 feet, but the evidence for them is fragmentary and certainly not decisive.

The Sussex Coastal Plain

The continuation of the Solent belt of terraces can be traced in the country immediately east of Southampton Water, but beyond Fareham the anticlinal Chalk ridge of Portsdown confines the coastal plain to a narrow and low-lying

* Some of the terrace names proposed by Green are used in the literature of the subject, so we may give them here: VIII, Upper Ambersham Terrace; VII, Ambersham Terrace; VI, Sleight Terrace; V, Boyn Hill Terrace; IV, Upper Taplow Terrace; III Lower Taplow I Terrace; II, Lower Taplow II Terrace. Green also recognized sub-divisions of the flood-plain gravels which we shall not here discuss. Only one of the terraces (VI) has a local name, and though the correlation implied in terraces II-V and VII and VIII may well prove sound, it seems premature to 'beg the question' by giving these definitive names.

† Everard's figures indicate an interval of 55 feet, agreeing thus with Sealy's figures for the Test. In the Avon it would appear that Sealy's lower (or downstream) figure for terrace V is probably too low. Further upstream, near Ringwood, the interval is closely similar to that for the Test and Solent series.

strip largely covered by alluvium. Beyond Havant the main gravel plain sets in again at the foot of the dip-slope of the South Downs and near Chichester its width exceeds 10 miles. Behind it is a well-marked bluff cut in Chalk; from Westbourne to Arundel, a distance of some 15 miles, the landward edge of the gravel sheet lies within a quarter of a mile or less of the 200-foot contour at about 140–150 feet. Here evidently is the continuation of the feature we have noted in the New Forest area. The surface deposits below the bluff are not water-laid, but Coombe Rock or solifluxion gravels which have sludged down from the higher Chalk country. They are well exposed in pits near Slindon and both here and elsewhere they rest upon the well-known Goodwood raised beach of which the shingle and associated sands lie at about 100 feet. The beach was first discovered by Prestwich;[76] more recently it has seen studied by Fowler,[77] and by Curwen and Oakley,[78] who have obtained flint implements on or near the surface of the marine deposits.

There is no doubt that these beach deposits are distinct from the lower raised beach well known at Black Rock, Brighton. They range in height from about 80 to 135 feet. The few palaeolithic implements known from the deposits suggest that those at about 80–90 feet may be older than those at a higher level. However, this may be, there is general agreement that they mark the period of rising base-level which caused the major aggradation of the Boyn Hill stage. We have, in fact, an old marine strand buried beneath later Coombe Rock deposits: it evidently affords an important datum line in interpreting the geomorphology of our area as a whole.

Of the remaining deposits of the Sussex coastal plain we shall not here speak in detail. The Brighton raised beach rests on a platform at about 30 feet O.D., but its upper surface, prior to erosion, may have reached 45–50 feet O.D.:[79] it cannot be assigned to the '15-foot raised beach' as supposed by some writers. Palmer and Cooke[80] have claimed that there are, in fact, three raised beaches at about 100 feet, 50 feet and 15 feet O.D. respectively, but the evidence for this reading of the facts is at present incomplete. It is clear only that the Goodwood deposits, their off-shore equivalents, and any earlier or later marine deposits, are enveloped by a sheet of Coombe Rock, locally interstratified with and succeeded by brickearth. It is probable that more than one phase of Coombe Rock and of brickearth formation followed the recession of the Goodwood sea. In broad terms the record is evidently comparable with that of the Lower Thames valley; but precise correlation cannot proceed without well-tested archæological dating. It is clear, at least, that the high sea-levels of the Goodwood and Brighton phases were succeeded by a low sea-level phase in which the Sussex rivers cut deep channels since filled by alluvium during aggradation. The alluvial fill near Arundel exceeds 100 feet in thickness.

The South Downs

If we turn now to the morphology of the South Downs, we are assisted by two recognized datum planes, the Pliocene level and that of the Goodwood raised beach. The equivalents of the successive phases of Stages I and II, as we have traced them in the London and Hampshire Basins, are to be sought between these levels, and considerable success has attended the search for them.

In 1936, A. J. Bull[81] examined the spur-profiles of the scarp face of the South Downs and claimed evidence of erosion levels at 400, 320 and 200–220 feet. The two higher levels are developed in the relatively resistant Melbourne Rock at the

base of the Middle Chalk. It is a common practice, following a rather crude and elementary 'structuralist' view of landscape, to suppose, in such cases, that the hard rock element is the direct cause of the flat or bench associated with it. On immature slopes such structural rock-benches certainly occur, but, as Bull conclusively showed, such an explanation will not here avail. The flats are well-preserved when, and only when, the Melbourne Rock occurs at the significant level: it is the cause of the preservation, not of the formation of the benches.

The lower erosion surface at about 200 feet is a much more important feature and is developed on a wide range of rock-types: we shall discuss it more fully below. Bull also recognized benches in the river-gaps at about 200, 130 and 80 feet O.D., and suggested the correlation of the two lower members with the Boyn Hill and Taplow levels respectively.

In 1949, B. W. Sparks[37] attacked the same problem in a detailed study of the erosion surfaces of the dip-slope of the South Downs. For a hypothesis involving a series of negative shifts of base-level his results provide impressive support. At first sight, this rolling and much dissected Chalk country might appear to present most unfavourable conditions for such analysis. Nevertheless, Sparks found consistent evidence of planation at the following levels: 475 feet, 430 feet, 380 feet, 345 feet, 330 feet, 290 feet, 230 feet and 180 feet. In each case the height quoted is that of the back of the flat in question, i.e. the foot of the bluff or slope above it. Any simple structural control of the flats mapped must be entirely discounted in the light of the known structure of the area; the flats of any one group range widely across the outcrops of the several Chalk zones while maintaining their elevation.

The dominant physical feature of the area is the secondary escarpment, well seen at Cissbury, built by the topmost beds of the Chalk. Its crest frequently lies near the level of the Pliocene platform and Sparks draws a distinction between the flats developed south of the crest and those which break the slopes of the vale in front of it. The former are treated as marine flats and the bluffs which bound them as former coastline features. The latter are interpreted as sub-aerial or river-cut features; in many cases they are slightly higher than their supposed marine equivalents. We have commented above on some of the conclusions on drainage development drawn by Sparks on the basis of his platform sequence (p. 86).

The number of platforms mapped may appear, at first sight, embarrassingly large and it is fair to note that the type of interpretation adopted by Sparks has evoked strong protest when applied elsewhere. Nevertheless, it will at once be seen that his conclusions are entirely consistent with the general trend of recent research in South-East England. Moreover, it is difficult to deny that this is the type of record we should expect in the light of the general physcial history of the South Downs area. There can be little doubt that a Pliocene sea washed parts of the higher downland surface and none at all that the Goodwood raised beach, of early or middle Pleistocene age, follows the foot of the Downs west of the Arun. If the sea persisted in the English Channel region between these dates, the over-all movement of the strand-line has been downwards. But if this correctly pictures the general physical history, it is clear that the sea must have stood at least once and, if oscillation took place, more than once, at all levels between the limits we have set. It could not be possible in these circumstances to recognize more than the major phases of still-stand, and it may be useful, therefore, to make a broader grouping of the levels recognized by Sparks. There are, in fact, four main breaks

in the platform sequence, respectively at 430–445 feet, 345–355 feet, 240–260 feet and 180–200 feet. The several *groups* of levels above these breaks may be said to constitute the major features of the series. The 475-foot level has not yet been clearly distinguished elsewhere. A 430-foot level is widely known, not only in the London and Hampshire Basins, but in South-West England. The 330-foot level has its analogue in the Hampshire Basin, but the 290-foot level is not as yet widely recognized. Well-developed planation between 180 and 240 feet is common throughout South-East England. Here, however, we are within the range of Pleistocene strand-line oscillations and the record, if fully known, would necessarily be very complex.

The Weald

In the interior region of the Weald much work on the denudation-chronology remains to be done and it confronts considerable difficulties. Terrace gravels are, on the whole, poorly developed and little known, and while erosion surfaces may certainly be traced, they show a considerable range of height and present every evidence of being sub-aerial in origin.

There are strong suggestions of a phase of river-planation at about 400–500 feet. Thus the western end of the central sandstone core shows a strikingly regular summit plane at about 500 feet, while the northern flank of the same area, eastwards to Tunbridge Wells, is bevelled at a slightly lower level, above which the curious isolated eminence of Dry Hill, crowned by its Iron Age camp, rises like a monadnock. In the Weald Clay country to the north the long ridge, under-pinned by a band of Paludina limestone, which runs from near Horsham to the neighbourhood of Horley, culminates at 400 feet. To these scanty indications we may add the fact that the water-gaps of the northern rivers, notably the Mole, convey some suggestion of a 400-foot stage. The upper slopes of the Mole gap descend gently to about this level where they are cut off by the steep river cliffs which bound the trench of the main valley.*

A suggestive detail in the western Weald is the occurrence of isolated hills rising to the 300-foot level and capped locally by unassorted chert drift. A hill-top gravel cap of this character has been mapped by the Geological Survey near Newdigate. Further west, the long ridge followed by the country boundary east of Haslemere is capped by coarse chert drift for several miles eastward of the Hythe Beds escarpment at Blackdown and Hindhead. It is probable that this drift marks an early, perhaps the first, onset of periglacial conditions in the Weald and that it is derived from the debris of the gigantic slumps or land-slides which characterize the Hythe scarp here and may well have been themselves facilitated by periglacial conditions.[82] In any case it is clear that a surface must have existed over which angular chert rubble could be carried to these isolated hill-tops and the general agreement in their elevation with the features described by Bull and Sparks and with the so-called Sicilian terrace in the Hampshire Basin, is perhaps not without significance.

Of much greater regional importance is the widespread planation at about 200 feet O.D. Though the dissected plain in question extends beyond the Weald, it was here, in the Dorking area, that its presence was first detected. As noted

* We may recall the evidence that Lower Greensand chert was carried by the Mole to points on the 400-foot plateau, north of London, and we must necessarily envisage a stage in the drainage which permitted this transport.

above, it has since been traced by Bull along the foot of the South Downs, as well as in isolated remnants in the Hastings Sands country further north.

The occurrence of this 200-foot platform at Ambersham Common, near Midhurst, was adopted by J. F. N. Green[83] as a type-locality and made the basis of correlation far beyond the limits of the Weald. Since the locality was not fully described by him we may devote brief attention to it here.

Ambersham Common lies on the outcrop of the Folkestone Sands, two miles south-east of Midhurst. The higher ground forms a ridge trending from south-west to north-east, with its crest declining gently north-eastwards from a culminating point at 219 feet at its southern end. Here it is separated by lower ground from the Chalk escarpment, distant a mile and a half. The ridge is capped by a thin accumulation of angular white flint gravel. It is clear that the flint was derived from the Chalk before the hill-top was separated by erosion from the scarp base; it is a rubble which must have been emplaced by solifluxion under periglacial conditions and it shows some evidence of being a completely decalcified Coombe Rock.

The gravel cap is only one of a series displayed locally, as, e.g. on Midhurst and Graffham Commons. We may take leave to question whether it is, in fact, a good type locally for an 'Ambersham stage', applicable to the terrace sequence of the Solent or, much further afield, the Dart. It is, indeed, a typical relic of what we would term the '200-foot platform', but the ridge as a whole is not flat-topped; the gravels extend along its crest for nearly a mile, but at the lower end of the ridge they are well below 200 feet.

Whether the type-name be regarded as wisely chosen or not, it may well prove that the correlation proposed by Green is correct. Judged morphometrically, if not stratigraphically, the 200-foot platform is very prominent in the western Weald. It is seen in the Rother valley west of Midhurst and is strikingly developed on the Weald Clay, as around Plaistow. Moreover, a similar feature recurs, with closely similar relations, in the Lower Greensand area of East Kent and extends also over the eastern parts of the Hastings Sands outcrop around the Isle of Oxney. It is prominent, too, along the Mole valley south of Dorking and here we may see it in relation to the terraces of the Mole and indirectly to those of the Thames.

The Longitudinal Profile of the River Mole

The Mole was the first of the Wealden rivers to be studied by the Weald Research Committee of the Geologists' Association. A cardinal feature of the work was the interpretation of the longitudinal profile of the river by J. F. N. Green.[84] The headstreams of the Mole drain the northern flank of St. Leonard's Forest. We may select as the chief of these the stream descending from the higher ground west of the Brighton Road near Crawley. The fall is about 100 feet in the first five miles; northwards the gradient flattens, so that in the next six miles to Meath Green, near Horley, the fall is only 20–25 feet, and in the neighbourhood of Horley the gradient is much flatter than the average so indicated. At Meath Green there is a break in the profile – a knickpoint or rejuvenation head – and the river descends into a steep-sided little trench above the lip of which an older valley-floor survives as a gravel-covered terrace. In the local sense this is the 'first' or low terrace of the Mole. It is widespread around Horley with a surface level of 180–190 feet, and above Meath Green the river is flowing only just below this level.

Rising above the general level are steep-sided ridges and isolated hills which show flat and sometimes gravel-capped tops at or just above the 200-foot level. It is natural to envisage the correlation of these with the 200-foot platform or Ambersham terrace of Green, but in default of fossil or archæological evidence we have no means of dating the extensive lower terrace surface. Green attempted a solution of this problem by fitting a mathematical curve to the segment of the Mole profile above Meath Green and projecting it downstream in order to bring it into relation to the terraces of the middle and lower Mole and thus with those of the Thames. Adapting a method used by O. T. Jones for the River Towy, he showed that a close fit of this segment of the profile could be made with a curve corresponding to the formula: $y = a - k \log (p - x)$, where y is the height above Ordnance Datum, x, the distance in miles upstream from the confluence with the Thames at Molesey, and a and k are constants. For the segment in question they have values of 241·5 and 65 respectively. The greatest difference between the measured and the calculated heights above Meath Green is 3·4 feet. Green considered the coincidence of the measured and calculated curves 'sufficiently striking to justify some reliance on the results of the extension of the latter. In other words, it seems reasonable to expect a formula which has been found to give a close approximation to the height of a terrace for the upper 27 miles also to give the approximate height of the equivalent terrace over the remaining 20 miles of the river course'. Applying the method thus indicated he found that the calculated level in the Mole gap west of Mickleham Church is 149·7 feet. Here there is a well-marked terrace which on its riverward edge shows a surface height somewhat below 150 feet. Six miles further downstream, above the right bank of the Mole, north of Church Cobham, lies the well developed high terrace of Fairmile Common which can be confidently ascribed, following the Geological Survey, to the Boyn Hill stage. Here the surface heights are between 130 and 140 feet, while the calculated heights are between 136 and 142 feet. In general, the terrace surface 'lies somewhat lower than the curve would indicate, but probably within the limits of error of the method'.

By this reasoning Green correlated the 'Horley Terrace' of the Mole with its downstream equivalents and the Boyn Hill Terrace of the Thames. We have dealt at some length with this particular correlation because it was the first application of the method in our area and was widely used in later work by Green and others. We shall not pause here to examine the assumptions and possible errors of the method. It is sufficient to note that it yields results generally accordant with the denudation-chronology of the area and mutually consistent when applied to the rivers of southern England as a group. The Mole itself shows lower knickpoints, of which the chief is near Cobham Station. For some four miles below Leatherhead the average fall of the river is 4½ feet per mile, but in the vicinity of Downside Mill the river falls 7 feet in half a mile, descending into a narrow steep-sided trench, like that below Meath Green, well seen on the Portsmouth Road at Painshill Bridge. Green at first regarded the profile of the trench floor as graded to a level at about that of the present Thames: later he modified this view and regarded the trench as the head of the back-cutting associated with the Buried Channel of the Thames. Between the head of the Downside trench and the knickpoint at Meath Green there are at least three distinct knickpoints in the Mole curve, so that tentative correlations with one or more stages of the Taplow Terrace and with the Flood Plain Terrace may be envisaged. The segments between the knickpoints are not long enough, however, to permit any dependable application of the

'curve-fitting' method. Here, as in the Hampshire Basin and elsewhere, the Boyn Hill level is the essential datum: if this can be recognized at least the relative dating of local terrace series can be perceived. If Green's correlation of the Boyn Hill Terrace of the Mole be accepted, we can not only range the lower features in order, but, what is more important, we have a lower datum for the regionally important '200-foot level'. It will be noted that the relative position of this feature in the area south of London is consistent with our conclusion as to its age in the glaciated area north of the Thames. There can be no doubt that the 'base-levelling' at this date was in the fullest sense a regional phenomenon and the recognition of the 200-foot platform as its equivalent is an essential step in reconstructing the denudation-chronology of any part of the area.

CHAPTER XII

SUMMARY AND CONCLUSIONS

We have ranged too far in time and space to render it either easy or useful to recall in detail all the conclusions we have reached. Some of them, indeed, are important only in their local context but others throw light on the physical history of the area as a whole and to these we may give brief attention.

We have seen that early growth of the Mid-Tertiary structures both major and minor, took place during a long period before the main tectonic phase of late Oligocene or early Miocene times. In all the stages of growth, the form and structure of the buried Palaeozoic floor were important. The chief tectonic boundary in the area coincides fairly closely with the line of the Lower Thames valley. Southwards of this line where the Palaeozoic floor is at great depth, the cover rocks are strongly folded in a belt which ranges through Wessex and the Weald. Throughout this belt the closely spaced individual folds dominate the structure and relief, though on small-scale maps they appear subordinate to the broad anticlinal warping which separates the London and Hampshire Basins. North of the Thames valley line, where the floor is at small depth, there is no strong folding but only rather indefinite and discontinuous flexuring.

The beginning of the erosional history of the area is indicated by the unconformity between the Chalk and the early Tertiary rocks. A full cycle of erosion ran its course after the emergence of the Chalk sea-floor and, as a result, the upper divisions of the Chalk were removed from the greater part of the area. It is probable, indeed, that the Chalk cover was completely breached locally in the Wealden and South Midland areas, for pebbles derived from the Lower Greensand occur locally in the Eocene pebblebeds.

The sub-Eocene surface, essentially a peneplain trimmed locally by the waves of the Eocene sea, was exhumed in later times from beneath its cover of early Tertiary sediments and forms a distinctive facet of the Chalk country on the margins of the London and Hampshire Basins.

The Eocene deposits and the Chalk floor on which they rest were warped and buckled in the Mid-Tertiary movements. We can make a resonably accurate reconstruction of the form of the folds before they were eroded: the most difficult problem in the physical history of the area is the reconstruction of the sequence of events following the folding. Much of the evidence available for its solution is embraced in that most famous and extensive view of southern England which we obtain from the tower on the summit of Leith Hill.

Here, just above 1,000 feet above sea-level, our prospect embraces a dozen counties. The natural horizon line is some 40 miles distant, but the actual view, given maximum visibility, falls short or ranges further than this with the accidents of relief. What renders the view signal and notable is the fact that the major hill

ranges of the south country lie, for the most part, near the horizon circle and thus frame the regional picture. To the north-west the skyline is the level crest of the Oxfordshire Chilterns, continued north-eastwards to the Dunstable Downs and, on a clear day, even beyond the Hitchin gap to the Chalk ridge south of Royston. Westwards and south-westwards the view is restricted by the high bastions of the Lower Greensand at Hindhead and Blackdown, but behind them the western Downs above Selborne present a crest as level and featureless as that of the Chilterns. It is continued in the summit line of the South Downs and the high central Wealden crests of Ashdown Forest. In the northern foreground, seen in in much greater detail, the North Downs present a similar even summit.

In these facts lies the evidence for the theory that the south country has been sculptured from an uplifted plain of which relics are preserved in our highest hill summits. A plane, 800 feet above sea-level, would, indeed, pass close to all these summits. Leith Hill (965 feet), Blackdown (918 feet) and Hindhead (890 feet) would exceed it, as would also the highest points of the North Downs (877 feet), the South Downs (880 feet) and the Chilterns (852 feet). Crowborough Beacon (792 feet) just fails to reach it, as do many parts of the Chalk crest-lines.

This plain was regarded by Davis as the product of the age-long waste and river action which ensued in Mid-Tertiary times, after the strong earth ripples, distant ground swell of the Alpine storm, had thrown the south country from Kent to Somerset into parallel ridges and furrows and thus given birth to the first decipherable drainage system in the area. These first rivers produced the plain; thereafter, as it was uplifted, they dissected it, bringing into being the graceful lines of the present landscape with its broad lowland vales separated by scarp-bounded uplands through which the rivers, older than the hills they traverse, wind in narrow defiles.

Davis thus recognized an ancient land surface. In its later development, physiographic work in the south-east has become a study of this and other surfaces of differing dates and various degrees of preservation. The hill-top plain of southern England may be reckoned, in this sense, a Miocene surface; the product of atmospheric action during that Miocene period which, alone among the major time divisions of the geological past, is unrepresented by stratified rocks in Britain.

If we are to use the south-east as a clue and a measure for other British regions we must take note of the fact that another well-marked surface can be traced in its landscapes. Younger than the main hill-top plain is the broad bench, cut largely in Chalk, on which the remnants of marine Pliocene deposits are widely distributed. This was not treated by Davis for, though Pliocene submergence was in his day known to have occurred in Kent, the full extent of the sea was not then recognized. The character of the deposits themselves, their occasional fossils, and above all the evidently wave-cut flat on which they rest and which is recognizably preserved even when the deposits have been removed, enable us to trace the former extent of the sea. In making the reconstruction shown in the map (Fig. 18) we were guided by a further important consideration – the relation, or rather lack of relation, of much of the drainage to the structure of the underlying rocks. When England, south of the Thames, was first raised into closely spaced ridges, the main lines of drainage must have followed the furrows between them. But that is not at all what we find over much of the main belt of folding to-day. Frequently and systematically, north-south rivers cross the east-west fold axes at their strongest development. This is notably true in Sussex and throughout the Wessex Chalk

area. It was a major defect of the Davisian hypothesis that it failed to account for such features. It is true that the first cycle of erosion would have obliterated the anticlinal crests, but if the present drainage were merely successor to that of the first cycle it could not, save by the local accident of river capture, have so developed as to cross the line of strong anticlinal folds. What is required to account for the facts is a new start for the drainage such as must have followed the spreading and subsequent uplift of a sheet of sand and shingle over parts of the old plain. It is worthy of note that it was Davis's student and chief successor, Douglas Johnson, who first hinted to us that an extension of the Pliocene sea into Wessex would satisfactorily account for drainage features otherwise hardly explicable.

Throughout the greater part of the area the Pliocene shelf or platform is backed by a low rise separating it from higher ground – part of the Mid-Tertiary plain. This rise fixes the position of the coastline. It is a feature of the greatest significance that the platform maintains a very uniform general level of about 600 feet. It slopes seaward from between 650 and 700 feet at the base of the rise to about 550 feet or a little lower. This shows beyond question that the late Tertiary uplift of much of South-East England was uniform, i.e. unaccompanied by faulting or bending. On the Essex coast, however, and northwards into East Anglia, Pliocene deposits contemporary with and later than those of the London area lie but little above sea-level; in Holland they are far below it. Thus is exemplified one of the later expressions of a long-established and recurrent tendency for the east coast region to be tilted towards the North Sea depression.

Excluding this eastern zone, the physiographic development of the area has consisted in the uplift and dissection, stage by stage, of the Pliocene sea-floor and the adjacent parts of the Mid-Tertiary plain. The stages of this uplift are marked by the minor platforms and terraces, essentially old valley floors, of which the district presents a complex but coherent record.

The fullest record is afforded by the London Basin, for here the sequence of river terraces can be related to the true glacial drifts. There is clear evidence that, following the retreat of the Pliocene sea, the ancestor of the Thames followed a line far to the north of London and marked to-day by the drift-filled depression of the Vale of St. Albans. Its southern tributaries carried Lower Greensand chert, which is found in the high-level hill-top gravels of the North London area and southern Essex. These gravels lie at about 400 feet above sea-level, north of London, resting on a surface which declines gently eastwards to about 300 feet in central Essex.

From its first northerly course the Thames was expelled in two stages of glacial diversion. The first was the work of a Chiltern ice-sheet, while the second was due to the advance of the main or great eastern ice-sheet deploying in its great terminal lobe from the neighbourhood of the Wash. It is difficult to trace the successive courses of the Thames across Essex, where the main drift sheet deeply buries the sub-glacial landscape, but there is a strong suggestion that the east coast estuaries, from the Stour southward to the Crouch, are lineal descendants of successive Thames exits to the North Sea.

In parts of the Middle Thames region, which lay beyond the furthest extensions of the great eastern ice, the shift in the course of the Thames has been steadily southwards and a full terrace sequence is displayed between about 400 feet O.D. and the present flood-plain. The higher terraces are attributable to the phase of the early or Chiltern glaciation or to the inter-glacial period which followed it.

In particular, the Winter Hill Terrace, the lowest member of the higher group, has yielded flint implements which place it clearly within the First Inter-glacial period. In interpreting the physical history of these higher terraces and of their lower-level analogues, well developed in the Lower Thames valley through London, it is clear that we must reckon with a base-level oscillating in harmony with the waxing and waning of successive ice-sheets and although the terrace sequence as a whole implies 'uplift', or an overall fall of base-level, the record is punctuated in the lower valley by episodes of submergence and aggradation.

The South Coast area, comprising the Sussex coastal plain and the Hampshire Basin, reveal a closely similar terrace sequence to that of the Lower Thames valley, though exact correlation of apparently equivalent terraces can hardly yet be proved by precise evidence. The area supplements the Thames valley record in one important particular since it yields clear evidence of one of the high sea-level phases, represented by the Goodwood raised beach, which may be regarded as marking the date of the great aggradation evidenced in the High or 100-foot terrace of the Thames.

In the South Downs and the Wealden area the full sequence of denudation-chronology is at present less completely known. The South Downs dip-slope displays the dissected remnants of a number of benches between 475 and 180 feet O.D., which may well be of marine origin. In the Weald there are indications of a general platform level at 400–500 feet O.D., which may well be the equivalent of the 400-foot platform prominent north of London and also represented in the South Downs and the Hampshire Basins.

Much more prominent and regionally significant to both the geologist and the geographer is the 200-foot platform – the Ambersham stage of J. F. N. Green – which is well marked throughout much of the Weald and present also in the Hampshire Basin and the central parts of the London Basin. This marks the most widely spread episode of river planation since the emergence of the Pliocene sea-floor. In a broad sense it is probably contemporary with the Winter Hill stage in the Thames valley. It was uplifted and to some extent dissected before the advance of the main or eastern ice-sheet into Essex.

We have seen that the essentially unwarped attitude of the Pliocene platform shows that strong differential movement has not occurred throughout most of the area since the Mid-Tertiary folding. For this conclusion the mutual relations and ready inter-regional correlation of the lower platforms and terraces afford independent support. It appears, indeed, very probable that the later stages of land sculpture have been largely under the control of eustatic changes of sea-level. This conclusion is not applicable, however, to the eastern margin of the area where the evidence suggests the periodic resumption of down-warping towards the North Sea depression. The western hinge of the warped area in Essex appears to lie along a roughly north-south line through Braintree.

The complex history thus summarized constitutes merely the closing stages of the long geological history of our region – the story of the shaping of its land-surface. As such it is inescapably part of the field of study of the geologist and it throws light on the physical history of much of the rest of Britain. But if we now revert briefly to the theme of our introduction, it will be clear that these complex episodes, seen in terms of their imprint on the face of the country, provide an important key to the character of that country as the home of man.

We may see the matter in fitting perspective if we take as our point of departure Mackinder's famous paper of 1887 on the 'Scope and Methods of Geography', read to a rather puzzled and perhaps slightly resentful audience at the Royal Geographical Society.[85] This was essentially the founding document of modern British geography. It was concerned to show that physical geography and what was then called 'political (i.e. human) geography' were two related stages of one investigation not to be divorced from one another, and that the approach to physical geography must be genetic. As an example Mackinder traced the broad structural features of South-East England, the work of erosion upon them and their relation to the pattern of drainage. Let us quote parts of his description:

> 'Let us try to construct a geography of South-Eastern England which shall exhibit a continuous series of causal relations. Imagine thrown over the land like a white tablecloth over a table, a great sheet of Chalk. Let the sheet be creased with a few simple folds, like a tablecloth laid by a careless hand. A line of furrow runs down the Kennet to Reading, and then follows the Thames out to sea. A line of ridge passes eastward through Salisbury Plain and then down the centre of the Weald. A second line of furrow follows the valley of the Frome and its submarine continuations, the Solent and Spithead. Finally, yet a second line of ridge is carried through the Isle of Purbeck and its now detached member the Isle of Wight. Imagine these ridges and furrows untouched by the erosive forces. The curves of the strata would be parallel with the curves of the surface. The ridges would be flat-topped and broad. The furrows would be flat-bottomed and broad. The Kennet-Thames furrow would be characterized by increasing width as it advanced eastward. The slopes joining the furrow-bottom to the ridge-top would vary in steepness. . . . The moulder's work is complete; the chisel must now be applied. The powers of air and sea tear our cloth to tatters. But as though the cloth had been stiffened with starch as it lay creased on the table, the furrows and ridges we have described have not fallen in. Their ruined edges and ends project stiffly as hill ranges and capes. The furrow-bottoms, buried beneath the superincumbent clay, produce lines of valley along the London and Hampshire Basins. Into the soft clay the sea has eaten, producing the great inlet of the Thames mouth, and the narrower but more intricate sea-channels which extend from Poole Harbour through the Solent to Spithead, and which ramify into Southampton Water and Portsmouth, Langstone, and Chichester Harbours. The upturned edge of the Chalk-sheet produces the long range of hills, which, under the various names of Berkshire Downs, Chiltern and Gogmagog Hills, and East Anglian Heights, bounds the Kennet-Thames Basin to the north-west. The North and South Downs stand up facing each other, the springs of an arch from which the key-stone has been removed. The same arch forms Salisbury Plain, and its eastward prolongation in the Chalk uplands of Hampshire; but here the key-stone, though damaged, has not been completely worn through. Beachy Head and the North and South Forelands are but the seaward projections of the Down ranges. The fact that the North Downs end not in a single promontory, like Beachy Head, but in a long line of cliff, the two ends of which are marked by the North and South Forelands, may serve to draw attention to a relation which frequently exists between the slope of the surface and the dip of the strata'.

He then enforced his argument and illustrated his general method as follows:

> 'This being the general anatomy of the land, what has been its influence on man? In the midst of forest and marsh three broad uplands stood out in early days, great openings in which man could establish himself with the least resistance from nature. In the language of the Celts they were known as "Gwents", a name corrupted by the Latin conquerors into "Ventæ". They were the Chalk uplands with which we were familiar, the arch-top of Salisbury Plain and Hampshire, and the terminal expansions of the Chalk ranges in East Anglia and Kent. In East Anglia was Venta Icenorum; in Kent and Canterbury we still have relics of another Gwent. The first syllable of Winchester completes the triplet. In later, but still early times, they were the first nests of the three races which composed the German host. The Angles settled in Norfolk and Suffolk, the Jutes in Kent, the Saxons in Hampshire. In still later England, Winchester, Canterbury and Norwich were among the chief mediæval cities'.

In these passages Mackinder shows the high power of graphic generalization which availed him so often and so greatly to the profit of the subject. Yet his account is notably incomplete and in some respects definitely erroneous. At the time when he wrote, Whitaker's *Geology of the London Basin* had been published for fifteen years, but hardly dealt with the physiographic history of the area. Topley's *Geology of the Weald* had been available for twelve years. From this great work Mackinder certainly derived inspiration; it foreshadowed many of the problems we have here discussed and made almost the first thorough attack upon them. But a further eight years were to elapse before W. M. Davis, completing the work of British pioneers, first spoke clearly in terms of the successive *stages* of development of the southern English landscape – of cycles of erosion. It is this method of interpretation which is necessarily absent in Mackinder's account: the 'chisel' has been applied not in one long uninterrupted period of demolition but in successive decipherable stages, each of which has left its mark on the landscape. Not until 1901 did Herbertson, Mackinder's colleague in the Oxford School of Geography which he founded, refer to 'this whole great new science' of geomorphology, realizing how much it was to mean not for the geologist only but also for the geographer.

Fully to utilize the findings of geomorphology in a geographical description of South-East England would be a task beyond our present compass. It would involve a full and careful division of the area into physiographic regions, so that what the theorists of the subject call its natural 'areal differentiation' might be brought out. This we shall not here essay, contenting ourselves with reference[86] to certain attempts to deal with the problem. But we may conclude by calling attention to a few of the salient physical contrasts in the area, which have guided its human development, but which are explicable only in terms of the full physiographic sequence we have traced.

It is, of course, evident that many of the chief contrasts within the area are directly attributable to the character of the rocks. Wherever the Chalk directly adjoins Eocene terrains a striking local regional boundary is to be seen, and where sand and clay make their frequent contacts within the Weald the fact is writ large in the landscapes. Lateral variation within some of the major formations is not less geographically significant. The sudden on-coming of Blackheath pebble-beds, east of Croydon, determines the fashion of the plateau country of South-

East London, while the thickening of the Thanet Sands from London eastwards through Kent is the basis of the distinctive belt of country which follows the line of Watling Street to the coast. Similarly the westward thickening and change of character of the Lower Greensand in the Weald is answerable for marked scenic contrasts expressed not only in land-forms but in settlement and agriculture.

All this and much more is contributed directly by the geological map to the geographical description and explanation of the country; in such terms, somewhat elaborating Mackinder's broad structural picture, we can discern the nature and cause of many regional contrasts. But our analysis is still notably incomplete unless we take account of the sequence of landscape shaping. This may be illustrated by reference to the varying character of the Chalk country, the consequences of the course of drainage evolution we have traced, and the complex legacies of the Pleistocene ice age.

Few types of country have been more carelessly misunderstood or more widely misrepresented than that of the English Chalk. The salient and memorable characteristics of the South Downs have become the basis of a sort of myth concerning the open and down-like character of our Chalk upland country. For the greater part this shows no 'blunt, bow-headed, whale-back downs' but level-topped, thickly-wooded uplands. Some of the statements made of such country suggest that the writers can never have visited it. Concerning the foundation and rise of Roman London we are told that 'a geological map indicates the necessary direction of communication from the Kent ports, that, namely, along the open heights of the northern Chalk downs'. From such an error the geological map itself will save us, if it shows the Clay-with-Flints and associated plateau deposits, with their heavy cold soils, still thickly wooded. There is no reason, indeed, to suppose that even the bare Chalk of the South Downs was free from woodland at the time of man's first advent in the area, but it is quite certain that the summit plateaux of the North and the Hampshire Downs and the greater part of the Chiltern upland were densely and perhaps almost impenetrably wooded. Our analysis has provided a means of discriminating three different types of Chalk country, according as the dominant surface is sub-Eocene, sub-Pliocene or relict of the great Mid-Tertiary hill-top plain. On the latter, chiefly, longest exposed to the weather, is a full growth of true Clay-with-Flints to be found, but the Pliocene platform both in the Chilterns and the North Downs is sufficiently mantled with stony clay or loamy drifts to give rise to very similar surface conditions. Only on the lower dip-slope, stripped of its covering of sandy Eocene beds, do we find soil conditions favouring arable cultivation and presenting opportunities for the early clearing of woodland. It is a zone, also, not too far removed from underground water and sometimes, as south of London, furnished with springs at the Eocene junction. It was country of this type which provided the 'Gwent' of Kent of which Mackinder speaks; nowhere, indeed, can the contrast between the sub-Eocene and the sub-Pliocene facets of the Chalk be more clearly seen than in East Kent, but it is valid throughout the North Downs to near Guildford, though less clearly marked in the Chiltern Hills. Here the contrast between the Pliocene shelf and those higher parts of the plateau which remained unsubmerged is clearly expressed in land-use; the scarp-crest tracts are in woodland and heath, while the Pliocene shelf forms cultivated ground. It remains to be seen how far legible soil differences exist between the two areas: much plateau brickearth comparable with true loess lies upon both surfaces.

The South Downs, now in a state of much more mature dissection, offer no contrasts such as these, though as we have seen, they exhibit a feature of their own in the secondary escarpment of the Belemnite Chalk, whose development was prevented in the North Downs by Eocene erosion.

The wider Chalk tract of Wessex can in no proper sense be treated as a geographical unit. We have noted (p. 70) that Hampshire and Wiltshire have significantly different physical histories. As a result the rivers of Wiltshire run in deep narrow tortuous valleys whose lush meadows and fine trees but heighten the arid monotony of the upland plain. From the first these streams were condemned to a history of slow incision into a massive outcrop of bare Chalk which their activities have made more and more waterless. The Hampshire rivers, on the other hand, found on the emerged Pliocene plain extensive outcrops of soft deposits and variety of structure which have led to the easy opening of wide smooth synclinal vales and a ready integration of the drainage system which is patently reflected in the flowing lines of a landscape whose features blend in a subdued harmony of upland and lowland impossible to match in the western country. Here essentially lay the 'Gwent' of Mackinder's analysis; its distinction from the Wiltshire upland is well marked in the Roman phase, for Romano-British villages cluster on the Wiltshire heights, but give place to villas in the Hampshire valleys.

The superimposition of the drainage of much of the area from a Pliocene cover was, as we have sought to show, a physical episode of the highest importance, and the valley pattern as a whole is only comprehensible in terms of this hypothesis. Nevertheless, its effects upon the country as a human environment are not everywhere regionally important factors. Yet the drainage unity of both Wessex and Sussex evidently derives from the act of epigenesis. This fact is easily lost sight of in Wessex if the structural complexity of the area is ignored or minimized. In Sussex the presence of strong longitudinal folding is plain enough and it at once appears that the unity of the South Saxon kingdom and the pattern of internal divisions into which it was resolved are a reflex of a direct coastal drainage which ignores this structure. Sussex embraces the greater part of the sandstone core of the Weald. Access to it was made easier by the narrow outcrop of the Weald Clay but it was also directly facilitated by the rivers and the sandstone ridges, often marked by ancient crestways, which separated them. The unity of the area, embracing Downs and Weald, owes much to the drainage pattern established after the Pliocene submergence and the medieval rapes of Arundel, Bramber, Lewes and Pevensey are essentially based upon their axial rivers.

Of the direct contribution of glaciation to the making of the country north of the Thames it is needless here to speak at length. If the drift cover were removed, much of Norfolk and Suffolk and parts of northern Essex would lie below sea-level. The range of generally loamy soils afforded by the drifts encouraged settlement and cultivation from the time of the Saxon entry, and by that of the Domesday Survey the East Anglian province stood out as one of relatively high population density. Nevertheless, the Norwich region, as distinguished by Mackinder, can in no sense be regarded as a Chalk 'Gwent' comparable with those of Kent and Wessex. This is a mistake that can only arise if we ignore the drift cover.

The drift cover made a similar direct contribution in the form of favourable soils and readily available water, to the economy of the pre-Roman Belgic kingdom of the Catuvellauni, the head of the confederacy opposing Caesar's invasion. The

municipium of Verulamium, successor to a Belgic city and ancestor of St. Albans, was, for a time, in some sense the capital of southern Britain, with London as its port.

Physical history has still further laid the foundation of human development in the London area. The Vale of St. Albans which marks the line of the early Thames is more than a belt of drift deposits: it is a longitudinal hollow lying athwart the course of the Chiltern drainage and serving to trap and divert a large share of the underground flow of Chalk water towards London. Here is the Chadwell spring from which Hugh Middleton's curious aqueduct of 1613 – the New River – brought water to London, and here to-day the water companies of the northern fringe of London sink their wells.

While the presence of the ice in the north-east of the region poured floods of outwash material into the Thames drainage system and added materially to the extent of its gravel spreads, the diversion of the main stream and the successive southward shifts of the channel caused the gravels to cover wider spreads of country ranging much further south than would otherwise have been the case. The outcrop of the London Clay which might well have given rise to an unbroken belt of wooded and intractable clay country was thus considerably diversified. In short, the early Thames and its diverted successors deposited the gravels which form the permeable hill cappings of the area north of London, providing thus the sites of the predominant and characteristic hill villages of the pre-urban countryside. Further, the diversions of the Thames, by bringing into being the lower courses of the Lea and the Colne went far to define the natural 'territorium' of Roman London and laid down the limits of Middlesex, the sole surviving evidence of the enigmatical Middle Saxons, otherwise lost to history.

Finally, we may note that the Lower Thames valley as we know it to-day is a direct legacy of the events we have traced and is itself responsible for some of the major features in the geography of England. It is permissible to wonder whether the course and outcome of the Roman and Jutish invasions of Kent would have taken the form we know if Kent had extended northwards across a broad zone of forested clay country to a Thames whose estuary lay in Essex, north of the Rayleigh Hills. To argue thus is no doubt to open up a vast and vague field of perhaps rather profitless speculation and to use a method which historians in general might condemn. It serves, nevertheless, to bring into relief the high significance of the physiography of the Lower Thames region as we know it. More certainly may we see that Thames-side with its tide-water Chalk quarries and sea-borne coal owes much of its industrial quality and aspect to the events which placed the Thames estuary where it is. In general, the whole geography of the site and situation of Roman, medieval and modern London reflects the long course of the preparatory processes whose sequence we have traced. 'Nature', it has been said, 'prepares the site, all else is the work of man', yet nowhere more than in the Thames valley does a just appreciation of the physiographic fundament illumine the significances of the human pattern growing from it.

In all these features, not less than in the symphonic composition of the hill and valley outlines themselves, the events of the recent geological past live on, serving to emphasize that in the field of human geography not less than in that of geology itself, the whole of the past is necessary to explain the whole of the present.

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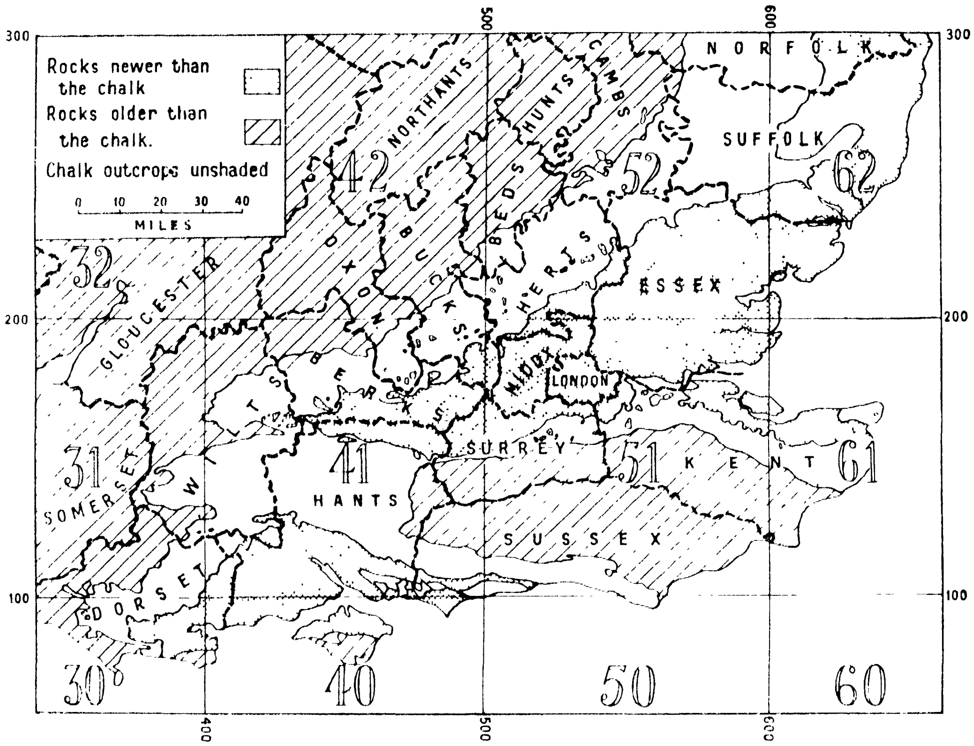

FIG. 32 – Grid reference map showing main geological outcrop.

INDEX OF PLACE-NAMES IN SOUTH-EAST ENGLAND

Place-names in the following index are those of streams, hills, towns and villages in South-east England mentioned in the text. Names of large towns and county and regional names are omitted: names of places overseas are included in the general index.

National Grid References are given for all places included. The first two figures define the 100-km. square in which the place falls: the location of these squares is shown on the map opposite, and a general idea of location of any place within the 100-km. square can be inferred from the rest of the reference. A closer approximation, and for most purposes sufficiently exact, can be obtained by reference to the Geological Map of England and Wales (Sheet 2), 1 : 625,000, which carries grid lines at 10-km. intervals and is very clear. For precise location reference must be made to the one-inch Ordnance Maps.

It should be noted that the use of numbers for the 100-km. square is obsolescent. The numbers are being replaced by two letters, the first referring to the 500-km. square and the second to the 100-km. square within it in which the point referred to lies. (See *The Projections for Ordnance Survey Maps and Plans and the National Reference System*, 1951, *H.M.S.O.*)

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52/572114	Abbess Roding, 129
30/577853	Abbotsbury, 75
52/095023	Abbots Langley, 113
51/200080	Adur R., Fig. 8, 23, 62, 79, 81, 82, 83, 84, 86, 87
62/464566	Aldeburgh, 45
51/140985	Aldenham, 114, 118
41/185274	Alderbury, 64, 69
41/866504	Aldershot, 51, Fig. 15, 54
51/038340	Alfold, 83
41/588326	Alresford, 68
51/910990	Althorne, 132
41/717393	Alton, Fig. 7, 18, 43, Fig. 15, 54, 58, 92, 94, 96
41/915195	Ambersham Common, 145
41/958973	Amersham, 101, Fig. 26, 108
41/976975	Amersham Common, 101
52/370126	Amwell, 107
41/365453	Andover, 16, 22, 29, 64, 68
51/957293	Appledore, 22
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51/222955	Arkley, 52, Fig. 15, 54, 103, 114, 115
51/543075	Arlington, 79
42/615136	Arngrove, 107, 109
51/020070	Arun R., 22, 29, 43, 76, 79, 80, 81, 82, 83, 84, 85, 87, 143

Nat. Grid Ref.	
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51/216950	Barnet Gate, 104, Fig. 25, 104
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51/078925	Batchworth Heath, 103
51/747160	Battle, 77
41/027320	Baverstock, 39

Nat. Grid Ref.	
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41/945900	Beaconsfield, 101, Fig. 26, 108, 110, 111, 112, 115
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